TAMPEREEN TEKNILLINEN YLIOPISTO
TAMPERE UNIVERSITY OF TECHNOLOGY

TEVFIKCAN COSKUN

MAKING USE OF SIMULATION FOR PRODUCTION SYSTEMS IN IMPLEMENTATION OF INDUSTRY 4.0

Master of Science Thesis

Examiner: prof. Hannu Kärkkäinen
Examiner and topic approved on 14th May 2018

ABSTRACT

TEVFIKCAN COSKUN: Literature review: Simulation approach in production systems for implementing Industry 4.0
Tampere University of Technology
Master of Science Thesis
May 2018
Master's Degree Programme in Industrial Engineering
Major: Industrial Management
Examiner: Professor Hannu Kärkkäinen

Keywords: Simulation, Industry 4.0, Production systems, Manufacturing, manufacturing systems, literature review, production processes

Industry 4.0 is one of the novel paradigms and the most talking topics in the recent years, there are many resources about it in literature for almost all the industry sector. Industry 4.0 is defined as the fourth industrial revolution, because it provides a wide and new range of possibilities to the Industry. Recent advances and trends of some key technologies such as actuators, sensors, cloud computing and big data analytics make Industry 4.0 possible. Industry 4.0 is a broad subject and there are many concepts related to it for example, cyber physical systems, smart factory and Internet of Things, etc.

Industry 4.0 brings many benefits and challenges, together. In order to eliminate these challenges and increase the benefits of Industry 4.0 implementation, simulation modeling of a system is a one of key approaches using in literature for decision making and provides many other possibilities.

This study aims to state possibilities of using simulation approach for implementing Industry 4.0 in production systems by reviewing literature. Simulation have used in industry since the third industry revolution but it has to be effective and dynamic after the forth industrial revolution due to the huge amount of data collected from products, processes, machines and devices.

The current study started with the investigation of Industry 4.0 paradigm, its technologies and challenges. Then, simulation approach and its types are defined. Finally, Literature was also reviewed according to defined literature review methodology.

The results showed that the simulation approach is very useful to eliminate the challenges of the Industry 4.0 implementation. Furthermore, simulation and new technologies (e.g. Virtual Reality), together, can be used to meet visualization requirements of Industry 4.0. Simulation also provides validation of proposed algorithms for Industry 4.0 implementation.

PREFACE

This study explores the possibilities of simulation approach for implementing Industry 4.0 technologies in production systems.

I would like to thank in the first place Prof. Hannu Kärkkäinen for being a such a good advisor, for giving me the opportunity to study in this multicultural university and this remarkable research. Secondly, I would like to thank Karan Menon for all his support and guidance through the whole research process, for being by my side and helping me to overcome the difficulties. Finally, I would like to mention my parents and friends for all their continuous support and allowing me to have this experience during the study period.

Istanbul, 08.05.2018

Tevfikcan Coşkun

CONTENT00S

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

CPS	Cyber Physical Systems
IoT	Internet of Things
IIoT	Industrial Internet of Things
PaaS	Platform as a Service
IaaS	Infrastructure as a Service
SaaS	Software as a Service
WSN	Wireless Sensor Networks
IT	Information Technology
IWN	Industrial Wireless Network
SME	Smart and Medium Size Enterprise
M2M	Machine to Machine
VR	Virtual Reality
RFID	Radio Frequency Identification
RQ	Research Question
ICT	Information and Communication Technology

1. INTRODUCTION

1.1 Research Background and Research Area

The Internet was a revolution in the computer and communications world. Adoption of the Internet started in the middle 90s and the technological advancement have been continued very fast until this day. The last evolution of the Internet is called Internet of Things (IoT) that refers to a new world. Internet of Things means virtually the physical things (all the big and small things) in the world can be connected and communicate between them. Furthermore, they can turn into a computer which is connected to the Internet. Internet of Things and recently, the emerging technologies (such as wireless sensor network, big data, cloud computing, etc.) started being applied to manufacturing environment then it is referred to the Industry 4.0 (Wang, Wan, Zhang, Li, & Zhang, 2016).

The concept of Industry 4.0 was first introduced and adopted as a part of "High-Tech Strategy 2020 Action Plan" by the German government. The similar strategies were also proposed by other main industrial countries, for instance, "Industrial Internet" from USA (General Electrics introduced in 2012) and "Internet +" from China (Wang, Wan, Zhang, Li, & Zhang, 2016). It is a new paradigm for the industry and opens a new world of possibilities and services. The features of Industry 4.0 have the potential to significantly increase productivity in manufacturing systems.

On the other hand, Industry 4.0 also brings a couple of challenges. In order to cope with these challenges, simulation modeling for the systems having global sensors and a large amount of data which keep arriving and changing is a one of key approaches for decision making and provides many other possibilities.

There is much literature trying to eliminate challenges of Industry 4.0 implementation by using simulation approach in manufacturing systems, but there is no literature review and analysis study about this literature. (Negahban & Simith, 2013) presented a literature review and analysis study about simulation for manufacturing systems design and analysis, but they stated a review of only discrete event simulation publication published between 2002 and 2013 and they also did not focus on Industry 4.0 technologies in production system . Another study, (Oesterreich & Teuteberg, 2016), stated the state of practice of Industry 4.0 relating technologies only in construction industry by reviewing literature. They mentioned Industry 4.0 technologies, however simulation is not key point in their study and they focused only a specific sector, construction industry.

This fact brings up a research gap to investigate available literature related possibilities of simulation approach for Industry 4.0 implementation in production systems. This report also studies the use of Industry 4.0 and the related concepts of IoT/IIoT, CPS, etc., as well as simulation used in them. The research gap of this study is shown in the Figure 1.

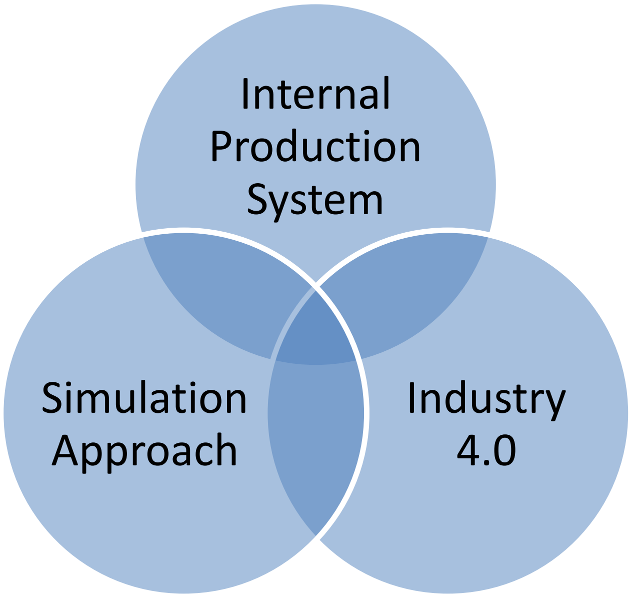

Figure 1. *Research gap of this study*

1.2 Research Questions

In order to address the research gap and taking into consideration the research gap presented in the previous section (see Figure 1), it is possible to formalize the following overall research question of the report which is going to guide the research process:

> *What kind of possibilities do the different simulations provide for implementing Industry 4.0 technologies in case of internal production systems/processes?*

The main question has a too long scope that difficult the research. In order to organize and facilitate the study, some specific questions were created and will support the main question that comes from the previous explained research background and area during the development of the report:

> *RQ1. What are the Industry 4.0 technologies in internal production systems/processes?*

RQ2. What kind of challenges are there for implementing Industry 4.0 technologies in case of internal production systems/processes?

RQ3. Why is simulation required and Where can simulation be used in overall?

RQ4.What kind of different simulation methods are there in overall?

RQ5.How do certain types of simulation that we focus on help to respond to the challenges of Industry 4.0 of internal production systems/processes?

RQ6.What are the benefits of simulation approaches for implementing Industry 4.0 technologies in internal production systems/processes?

The formulation of the research questions follows a logical thread; the first four questions are answered using the existing theory and the two last questions are answered using the literature review method and analysis.

This study about Industry 4.0 paradigm and simulation approach; thus, in order to answer the main question, in the first place, we should understand the Industry 4.0 technologies that make it possible (RQ 1), simulation approach and simulation types using in production systems (RQ 3 and RQ 4). After the main the concept and approach are clear, how simulation addressed the challenges (RQ 5) and benefits of simulation for implementing Industry 4.0 in production systems (RQ 6) are crucial in order to state the possibilities that different simulations provide. Thus, the question fifth and sixth are the major research questions of the study. All of the research questions help to answer the main research question. In the next sections of this study, we tried to answer all of these research questions.

1.3 Structure of The Study

This section aims to explain the overall structure of the study. In a general categorization, the structure of the study can be divided into four different main parts; introduction, investigation of the concept and the approach, literature review and analysis and conclusions (see Figure 2).

The first chapter of the study is the introduction. Firstly, Research background and research area are stated and an overall overview of the topic is also presented in this part. Secondly, the research questions related to the topic are defined.

The second part of the study can be divided into two sub-section. First section explains the Industry 4.0 concept and its technologies and challenges. Second section states simulation approach and its types and benefits in overall.

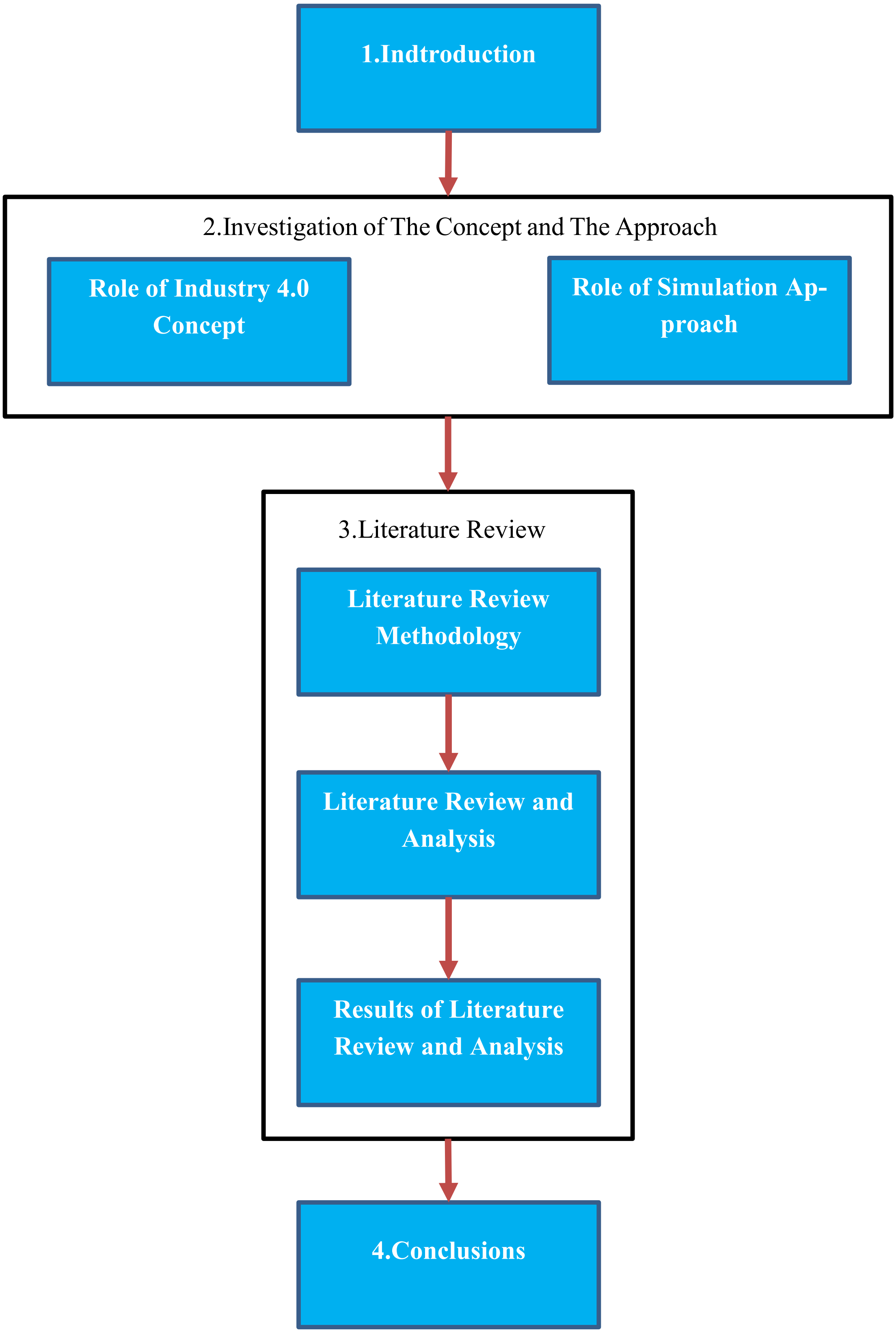

Figure 2. *Structure of The Study*

The third part of the study consists of literature review methodology section, literature review and analysis section and results section presented possibilities and benefits of simulation approach for implementing Industry 4.0 in manufacturing system.

Finally, the fourth part of the study is the conclusions. This part presents the conclusion of the whole study and tries to answer all research questions by summarizing and using previous chapters.

2. ROLE OF INDUSTRY 4.0 TECHNOLOGIES IN INTERNAL PRODUCTION SYSTEMS/PROCESSES

2.1 Industry 4.0 Concept

This section helps to answer the first research question (RQ1). This section provides definition of Industry 4.0 paradigm, its benefits and building blocks. By providing the information about Industry 4.0, the present section also aids to understand one of the main concepts of this research to answer the other research questions.

The term Industry 4.0 (or Industrial Internet) means the fourth industrial revolution and The German federal government coined the "Industry 4.0" term in context of its High-tech strategy in 2011 (Rodic, 2017) (Xu *et al.*, 2016). Before the Industry 4.0 was presented more detailed, other three industrial revolutions coming about as a result of mechanization, electricity and Information Technology (IT) were briefly stated as follows (Veza, Mladineo, & Gjeldum, 2016),

- The First Industrial Revolution – introduction of steam powered and water powered mechanical manufacturing facilities.
- The Second Industrial Revolution – introduction of electrically powered mass production based on the division of labor.
- The Third Industrial Revolution – introduction of IT and electronics to accomplish automation of manufacturing.

Evolution of the term Industry 4.0 used for the Forth Industrial Revolution and three other industrial revolutions was shown in the Figure 3 (Spoetti & Loose, 2015).

The Fourth Industrial Revolution can be stated as introduction of Cyber Physical Systems (CPS) and Internet of Thing (IoT) into the manufacturing environment and this new type of industry is based on Smart Factory model (Veza, Mladineo, & Gjeldum, 2016). While mechanical/ electrical/ digital innovations trigger the first three industrial revolutions, the advent of the Internet and its facilitation of communication between humans and machines in Cyber Physical Systems (CPS) triggered the Industry 4.0 (Xu *et al.*, 2016).

CPS is next generation of embedded Information and Communication Technology (ICT) systems. Networking and computing are integrated with physical process in the CPS. They also manage and control their dynamics. Thus, they become more secure, reliable, efficient and adaptable (Hermann, Pentek , & Otto, 2015).

Internet of Things is the vision where physical objects become connected and smart. Thus, they can not only send data to the environment and other objects but also receive data from the environment and other objects (Atzori, Iera, & Morabite, 2010).

Industry 4.0 is focused on the adoption of new computing and Internet based technologies, including cloud manufacturing, internet of things, cyber physical systems, digital and virtual reality, etc. to meet new challenges (Caggiano & Teti, 2018). Furthermore, according to (Kolberg & Zühlke, 2015), “Industry 4.0 aims for optimization of value chains by implementing an autonomously controlled and dynamic production.”

The implementation of Industry 4.0 needs many concepts and technologies including actuators (control elements), digital and networkable sensors, tablets as human-machine interfaces, cloud computing, integrated software solutions and industrial communication networks, the simulation modeling concepts, etc. (Rodic, 2017). These concepts and technologies provide availability of real time information and a communication interfaces. Thus, CPS can work autonomously and interact with production environment and as a result, a factory becomes ‘smart factory’ (Kolberg & Zühlke, 2015). A framework of the smart factory of Industry 4.0 briefly was shown in Figure 4 (Wang, Wan, Li, & Zhang, 2016).

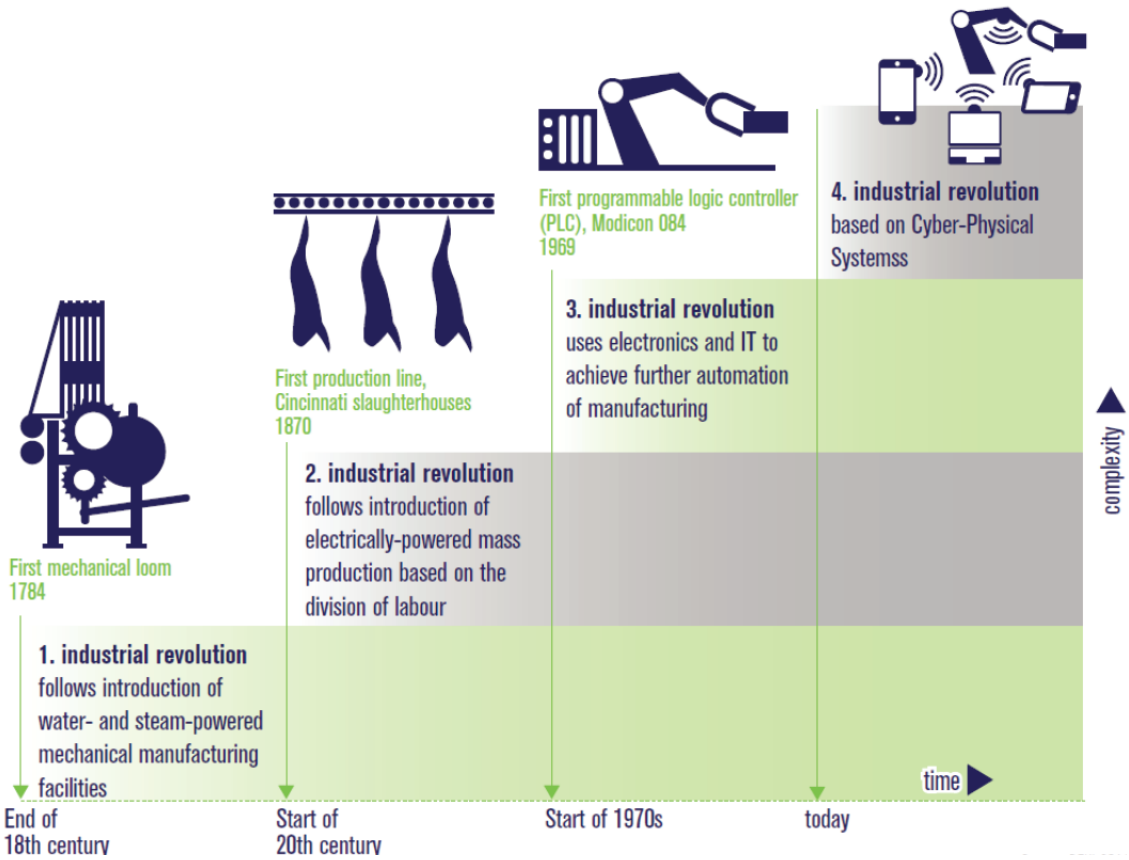

Figure 3. *Evolution of the industrial revolution*

(Gilschrist, 2016) states nine technological trends as building blocks of Industry 4.0. These blocks are:

- *Big data and analytics*
  Business cannot ignore the data coming from many various source. If business gathers data to collate, organize and use it in the analytics, data are very useful to optimization of production quality and service, improve efficiencies in the production process and reduce energy consumption.
- *Autonomous Robots*
  In the manufacturing systems, the use of the various robots is no longer new, but robots always need evolution and improvements with new technologies. With advanced technologies, robots are designed to be interactive, autonomous and self-sufficient, so that they are not simple tools used by humans. However, robots are already the work units functioning alongside humans.
- *Simulation*
  In order to create digital twins used for simulation modeling and testing, Industry 4.0 uses virtualization. They play major roles in the optimization of production systems.
- *Horizontal and Vertical System Integration*
  Production, marketing, after sales and engineering are closely linked in order to have a fully integrated operational technology (OT) and information technology (IT) systems aimed by Industry 4.0. Similarly, integrated companies in the supply chain give rise to collaboration at automation, fully automated value chains and data integration networks.
- *The Industrial Internet of Things (IIoT/IoT)*
  An essential part of Industry 4.0, made possible by IoT is embedded computing and networking which interact and connect devices/objects with each other.
- *Cyber-security*
  In order to protect industrial systems that becomes increasingly vulnerable from threats (e.g. hackers) and recognize challenges and vulnerabilities produced by industrial control systems that integrates with the Internet, cyber security have to put in place.
- *The Cloud*
  A large amount of devices generate the vast amounts of data in Industry 4.0 applications. Cloud service provides storage and processing of the huge amount of data for manufacturing systems.
- *Addictive manufacturing*

Additive manufacturing (e.g. 3D printing) facilitate the manufacturing and design of the products according to the customer expectations and also reduces design effort and time by enabling manufacturers to come up with proof of design and prototypes. It also provides production of small batches of customized products (Gilschrist, 2016) (Ustundag & Cevikcan, 2018).

- *Augmented reality*
  Augmented reality based systems reduce the costs by enhancing training and maintenance procedures of manufacturers (Gilschrist, 2016). Augmented reality can be used for visualization of production processes and specifications of qualified products or parts (Ustundag & Cevikcan, 2018).

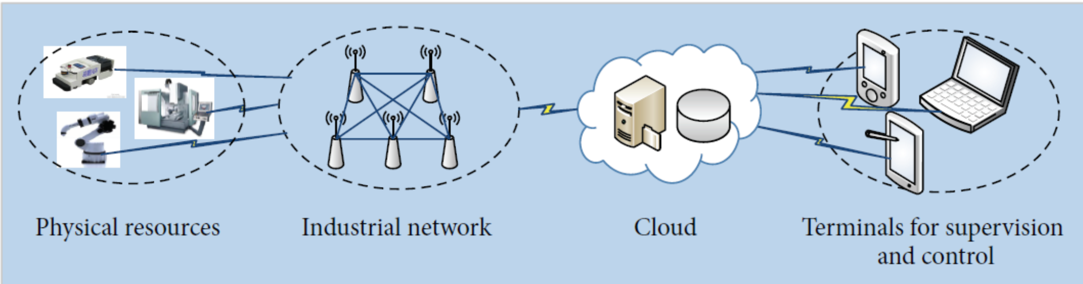

Figure 4. *A brief framework of the smart factory of Industry 4.0*

The main benefits of Industry 4.0 for SME were stated by (Gilschrist, 2016) as follows,

- *Increased competitiveness of business and flexibility resulting from dynamic structure of business processes* (Mrugalska & Wyreicka, 2017)
  Industry 4.0 allows small companies to work together for challenging large companies.
- *Increased productivity*
  The decrease of operational costs and the increase of efficiency leads to improvement of profits. This also increases productivity levels.
- *Increased revenue*
  Even though the implementation of Industry 4.0 needs significant investment, it is one of the major drivers for the improvement of the revenue levels.
- *Increased employment opportunities, enhanced human and IT resources management*
  Because the demand for works and talent in the fields of data scientist, mechanical technical work and engineering increases, employment rate also increase.
- *Optimization of manufacturing process*
  Integration of Information Technology and Operational Technology systems allows to develop industrial process and decision making is also done real time.
- *Development of exponential technologies*

Industry 4.0 leads to further innovation with developing technologies. They are used by developers and suppliers of technologies and manufacturing systems.

- *Delivery of better customer service*
  The methods and industrial concepts of real time provides monitoring and feedback mechanism for Industry 4.0. It allows decision makers to make intelligent decision, realize the current state and respond faster to customer needs and industrial process.

Furthermore, Industry 4.0 has a huge potential which is work-life-balance, high wage economy with reduced personal cost and cut energy costs, specialized industry specific solutions, individualized understanding of customers' needs, increasing resource productivity and efficiency (Mrugalska & Wyreicka, 2017);

2.2 Basic Technologies Related to Industry 4.0 in Internal Production Systems /Processes

This section helps to answer the first research question (RQ1). This section defines basic technologies related to Industry 4.0 in production systems. By providing these basic technologies, the present section also helps to answer research question five and six (RQ5 and RQ5), because it provides an idea about the technologies related to Industry 4.0.

There is no agreement for the right key enabling technologies or what should be considered as a technology related to Industry 4.0. For example, some academic papers (like (Kang *et al.*,2016)) present Cyber Physical System (CPS) as a technology, while some other papers (like (Ehret & Wirtz, 2016)) see it as a global and basic concept related to Industry 4.0. We also considered CPS as a main and basic concept related to Industry 4.0 in this study, after reviewing the most relevant literature and also following our own understanding.

(Montes, 2017) presents technologies related to Industry 4.0 and a possible categorization adapted from another study for the Industry 4.0 technologies in the Figure 5. It consists of three main categories: product/asset cloud, connectivity and physical product/asset. Physical product/asset contains technologies such as sensors, actuators and embedded operating systems. The second one, connectivity contains technologies that enable the product communication with the cloud or other products creating the network. The last one, Product/asset cloud category contains technologies such as servers, data analytics, platforms, storage, database, etc.

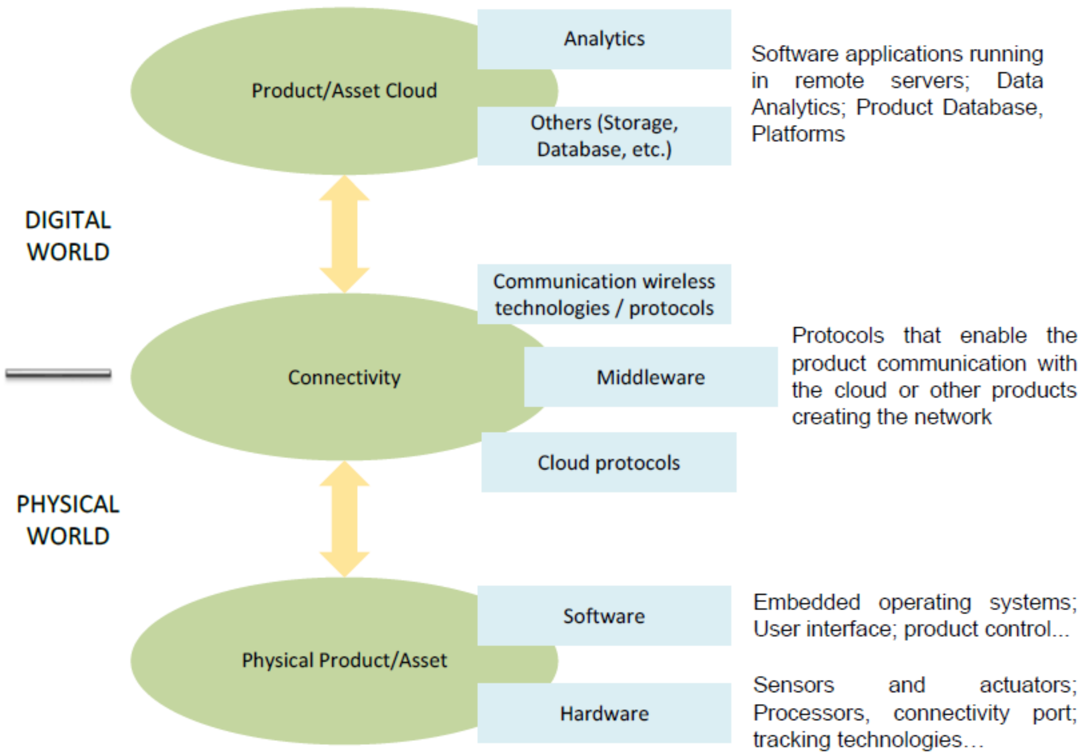

Figure 5. *Industrial Internet technologies and Categorization for Industrial Internet technologies*

We focused on the direct related technologies to Industry 4.0 in this study and the main and basic technologies (wireless sensor networks (WSN), actuators, Radio Frequency Identification RFID, middleware, big data and advanced analytics and cloud computing) were explained in more detailed as follows,

Wireless Sensor Networks (WSN)

Sensors are devices monitoring parameters of the manufacturing system such as humidity, vibration, quantity, temperature, etc. Sensors also create data about condition of manufacturing system and its context (Montes, 2017) (Ehret & Wirtz, 2016).

Sensors acts as an information interface and a bridge between physical devices (physical word) and digital world (e.g. the Internet) (Ehret & Wirtz, 2016).

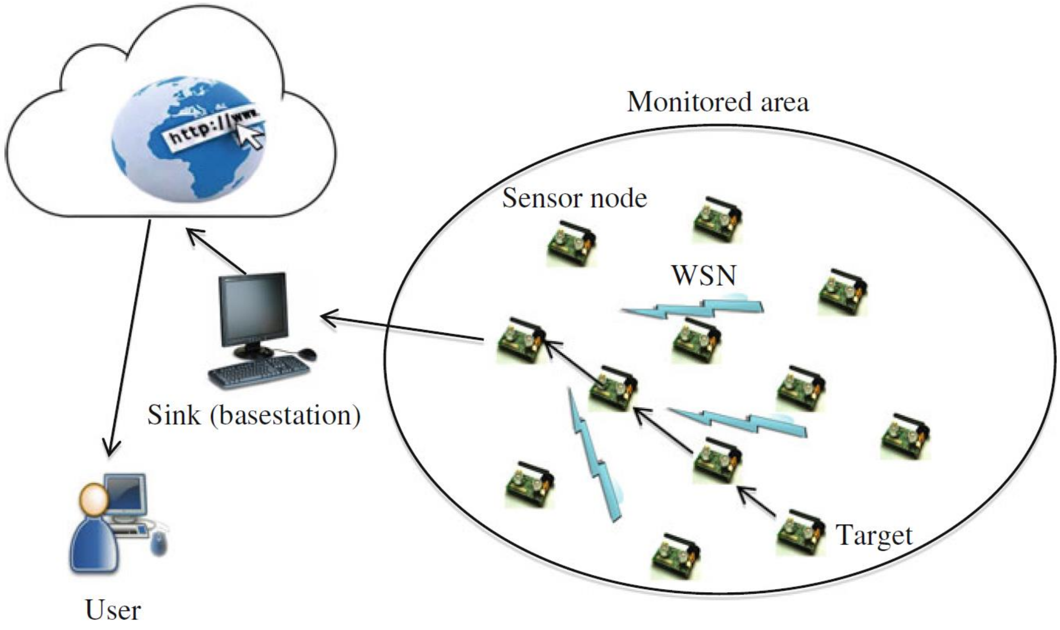

Figure 6. *Architecture of WSNs*

With recently advanced wireless communications technologies, multiple sensors (sensor nodes) are wirelessly used together and interact communicating between them so, they are called wireless sensor network (WSN). Wireless sensor networks play a crucial role for Industry 4.0 applications. But there are some main challenges related to wireless sensor networks, they are scalability, reliability, robustness and energy efficiency (Montes, 2017).

You can see the architecture of Wireless Sensor Networks built up of main entities in the Figure 6 (Fahmy, 2016).

Actuators

Actuators are components of automated systems driving movement and change (Ehret & Wirtz, 2016). Actuators can perform actions to affect the environment, while sensors monitor characteristics of the environment or products. Sensors are usually combined with actuators. It is called sensor-actuator networks (Montes, 2017).

Actuators can transform commanding signals into physical effects and modify in manufacturing system, for example laser cutting, moving robots or heating systems objects. Actuators (e.g. Internet connected actuators) allows operators not only to remote control the manufacturing systems and some manufacturing processes but also to conduct remotely maintenance and repair activities (Ehret & Wirtz, 2016).

Big Data and Advanced Analytics

Large (from terabytes to exabytes), complex (from sensor to social media) structured amounts of data which traditional databases and processing tools cannot manage is called as Big Data. Various sources such as video text, forms, web blogs and so on can create Big Data (Kang et al., 2016). A large amount of devices generate data in Industry 4.0 applications, due to the advances in sensor and wireless technologies (low cost, miniaturization, etc.). The size of this datasets is beyond traditional scales. Furthermore, it is difficult to capture, manage, storage and analyze this massive data collection for conventional database technology (Gilschrist, 2016). According to (Laney, 2001), data must possess the Three Vs: Volume, Velocity and Variety for being Big Data. (Laney, 2001)'s Three Vs is shown in Figure 7. Microsoft added two more: Value and Veracity and defined as the Five Vs (Buyya, Calheiros, & Dastjerdi, 2016).

The main problem is that how to handle these large, complex and unstructured data generated by environment, products and machines in order to potential knowledge and information. Technical, and special methodologies and systems related to analysis, search, storage, transfer, sharing, capture etc. are needed to solve this problem. In manufacturing industry an effective analysis, visualization and sharing of the data generated from manufacturing process is necessary for modelling and predictions (Kang, ve diğerleri, 2016).

The potential of these huge amounts of data and business efforts make possible predictive analytics (Data Analytics) to anticipate what will happen. It is expected to facilitate predictive of failures, when predictive analytics is applied to the manufacturing systems. Hence, costs can be reduced by preventing failures wastes of waiting, over production, excess inventory / safety stock, transportation and defectives (Ustundag & Cevikcan, 2018) (Gilschrist, 2016). After predictive analytics, next step is prescriptive analytics offering a solution to an identified problem. Advanced data analytics and algorithms are necessary to apply prescriptive analytics (Gilschrist, 2016).

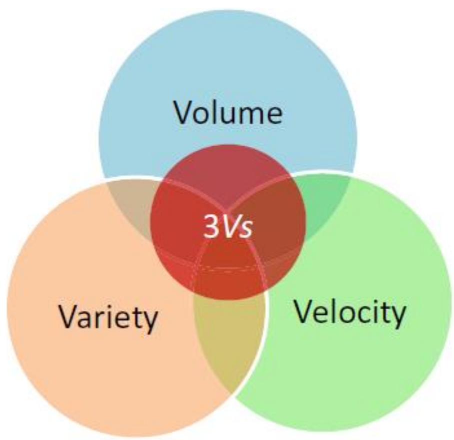

Figure 7. *The 3Vs of Big Data*

Cloud Computing

(Ustundag & Cevikcan, 2018) defines cloud computing as;

> "Cloud computing is an emerging parallel and distributed system that consists of interconnected and virtualized computers employed based on service – level agreements between the service provider and the customer."

Cloud computing frees the companies from setting up basic hardware and software infrastructures and associated investments. Thus, cloud computing provides significant benefits to the companies. IoT and Cloud computing, together, enhances intelligent communication and perception on a machine to machine (M2M) basis and on-demand and effective use of the resources, in the manufacturing systems. Thus, Cloud computing can eliminate wastes of waiting, efficient use of manufacturing equipment, unnecessary motion and processing to a certain extent (Ustundag & Cevikcan, 2018). In manufacturing industry, the term of cloud computing is often called as cloud manufacturing (Kang et al., 2016).

There are four types of deployments models (Mell & Grance, 2011);

- *Private cloud*
  A single organization exclusively uses the infrastructure. This organization, a third party or a combination of them can own, manage and operate it.
- *Community cloud*
  The infrastructure is shared between specific consumers and the ownership.
- *Public cloud*
  The infrastructure is shared with the general public.
- *Hybrid cloud*
  Hybrid cloud is a combination between two or more of the mentioned models.

Cloud computing has also three different categories from the service point of view (Gilschrist, 2016);

- *Infrastructure as a Service (IaaS)*
  IaaS is really interesting model for SME. Because SME can rent storage, compute and network from a provider instead of establishing a data center or server room and buying hardware. SME pay only what they used.
- *Platform as a Service (PaaS)*
  PaaS provides not only infrastructure but also access to software development languages, libraries, etc.

- *Software as a Service (SaaS)*
  SaaS is a new way of accessing software. Users use a web browser to access a web server shared application instead of accessing a local private server hosting a copy of the application.

In conclusion, the cloud offers solution to industry in order to process the huge amount of data (Big Data) produced by production system. For this reason, the cloud is a key technology for Industry 4.0.

Middleware

Middleware connects the Industrial Internet hardware generating huge amounts of data such as actuators, sensors, etc. with applications making use of this data for further analysis. Thus, the communication between different applications and objects that use different communication protocols is facilitated by middleware (Montes, 2017).

Five functional components are defined for IoT middleware by (Bandyopadhyay, Sengupta, Maiti, & Dutta, 2011) as follows,

- Interoperability
- Context detection
- Device discovery and management
- Security and privacy
- Managing data volume

Interoperability is the ability of components to exchange data and also the ability of independently developed components to interact and cooperate with each other.

Context is responsible to characterize the situation of an entity. Entity can be object, place or person related to the interaction between an application and a user. Context detection gathers identifies data and identifies the factor having impacts on the response.

Device discovery and management allows devices in the IoT network to find out their neighboring devices and then they know each neighbor in the network.

Security and privacy is responsible for non-repudiation, confidentiality and authenticity.

Managing huge amount of data is an integral part and an important module of IoT middleware.

Radio Frequency Identification (RFID)

Radio Frequency Identification (RFID) technology consists of one or more reader(s) and several RFID tags. RFID tags is a small microchip attached to an antenna in a package

(Atzori, Iera, & Morabite, 2010). RFID includes electronic information that can be communicated wirelessly via electromagnetic fields (Gilschrist, 2016).

There are three different types of RFID tag:

- *Passive RFID tags*
  Passive RFID tag is the most common used type that are not powered by battery to transmit their ID. Passive RFID tags use the power of the signal transmitted from the RFID reader.
- *Semi-passive RFID tags*
  The Battery powers the microchip while receiving the signal from the reader.
- *Active RFID tags*
  The battery powers the microchip and the signal. The cost of active RFID tags is higher than the other tags and this reduce applicability. So, they apply to high value items for example, containers for monitoring them (Gilschrist, 2016).

There are a lot of advantages of the RFID technologies. They do not need a direct contact with reader or a line of sight between the reader and tag when comparing them with barcodes. Multiple tags can be read simultaneously (Gilschrist, 2016).

2.3 Challenges of Implementing Industry 4.0 Technologies in Internal Production Systems/ Processes

This section helps to answer the second research question (RQ2). This section defines challenges of implementing Industry 4.0 technologies in production system, which have been defined in the literature. The present section also helps to answer research question five and six by providing the challenges of Industry 4.0 implementation, because simulation can be used for meeting some of these challenges.

(Müller, Kiel, & Vigt, 2018) stated challenges of the Industry 4.0 with the three main topics as follows;

- Competitiveness and future viability
- Organizational and production fit
- Employee qualification and acceptance

They will be explained below:

Competitiveness and future viability

Industry 4.0 takes place in a highly dynamic competitive environment. Furthermore, Industry 4.0 creates completely new and different industries, reshapes industry boundaries and exposes established manufacturing companies to new competitive challenges. For example, new competitors threat the current market position of established companies by releasing connected and smart product solutions or completely new business models.

Facilitated market entrance of new competitors and increasingly competitive dynamics are among the most important challenges in the Industry 4.0 era.

Furthermore, digital connectivity in the Industry 4.0 results in transparent business ecosystems facilitated by online platforms. Thus, high level transparency exposes companies to the risk of cyber - attacks, the challenge of securing data (access and rights) and industrial spying, because Industry 4.0 is largely based on internet – based and online.

Organizational and production fit

The implementation of Industry 4.0 has to be specifically planed for changing production and organizational scenario, such as regarding company size or different production structures.

Synchronization and coordination with existent production process and equipment can result in high costs and complexity levels especially for small and medium-sized enterprises (SMEs), if industrial manufacturers implement the Industry 4.0 in the form of isolated applications.

Employee qualifications and acceptance

In order to approach the new concepts and Industry 4.0 technologies, employees need to be qualified. Furthermore, businesses should have the employees having these qualifications; willingness to learn, creative problem solving in social settings, understanding network technologies as well as data analysis and processing and ability to find practical solution. Developing these qualifications is a challenge for manufacturers.

In this topic, another challenge is the acceptance of the Industry 4.0 technologies by employees. Employees' anxieties and concerns related to workplace safety in human – machine interaction system, data transparency and dependency on technical assistance systems play a significant role for the implementation of a new technology. Achieving Industry 4.0 – specific employee qualifications is another challenges in Industry 4.0 era.

Technical challenges in implementation of Industry 4.0 were presented by (Wang, Wan, Li, & Zhang, 2016) as follows,

- *Intelligent decision making and negotiation mechanism*
  Fundamental components of smart factory are the smart artifacts. Recently, the smart machines should have additional sociality and autonomy capabilities. Furthermore, the smart machines can make decisions by themselves.
- *High speed industrial wireless network (IWN) protocols*
- *Manufacturing specific big data and its analytics*

We should focus on special features of manufacturing related big data despite general big data analytics and the cloud computing. The main questions that should be answered are that which data should be collected, how these data can be collected, how to analyze the data and what is the meaning of the data.

- *System modeling and analysis*
  We need to model manufacturing system and conclude appropriate control methods in order to avoid from unexpected situation such as chaos.
- *Cyber and property security*
  We should protect various information on commercial strategies, suppliers, know-how and customer from threats such as hackers that can cause huge profit loss.
- *Modularized and flexible artifacts*
  We should develop smart and modularized conveying system which can reconfigure production routes dynamically. The modularized units with smart controllers provide easily adaptation of new machines to the system.

In order to eliminate these challenges and increase the benefits of Industry 4.0 implementation, simulation modeling of a system is a one of key approaches using in literature for decision making and provides many other possibilities.

3. ROLE OF SIMULATION IN INTERNAL PRODUCTION SYSTEMS/PROCESSES

3.1 Simulation Concept

This section helps to answer research question three (RQ3). This section defines simulation approach, its application area and building step which have been defined in the literature. By providing the information about simulation which is one of the concepts of this paper, the present section helps to answer research question five and six (RQ5, RQ6) because it provides an idea about simulation approach related to these questions.

There are many definition of simulation. Briefly, a simulation is the representation of the behavior of real system or process over period of time (Banks, Carson II, Nelson, & Nicol, 1984). Simulation approach has been used to forecast performance measurements, to answer the “what if” questions. Besides, simulation is common approach for analyzing, designing and optimizing complex systems, especially production systems.

There are many application areas of simulation. For instance, simulation can be used (Altiok & Melamed, 2001);

- Stating a set of performance metrics in manufacturing processes, material handling and transportation operations and inventory systems
- Evaluating and improving operation and system conditions, such as health care, airport, banking and financial operations and logistic systems aimed at finding ways of decreasing idle time.
- Evaluating the feasibility of proposed military operations
- Training students and practitioners (Singh, 2009)

The objectives of the use of simulation approach can be summarized as follows (Banks, Carson II, Nelson, & Nicol, 1984):

- Investigating the internal interactions of a complex system or of a subsystem within complex system.
- Observing the effect of informational, organizational and environmental changes on the model’s behavior.
- Contributing to improvement of the system under investigation with the knowledge obtained during the simulation study.
- Observing which variables are more important and how variables affect each other by changing simulation inputs and investigating results.
- Verifying analytic solutions.

- Observing effects of new designs and strategies on the system before implementing them in real system.

Simulation model building consists of basic eight steps (Altiok & Melamed, 2001).

1) *Problem analysis and information collection:* The analyst tries to understand the system and the system's problem. Later, a solution is mapped out.
2) *Data collection:* The analyst collects data related to system for estimating model input parameters.
3) *Model construction:* The analyst constructs a model and implements it as a computer program.
4) *Model verification:* The purpose of model verification is to make sure that the model is correctly constructed.
5) *Model validation:* The fit of model to measurement of the real life system is examined.
6) *Designing and conducting simulation experiments*: The analyst designs a set of simulation experiments to estimate model performance and solve system's problems.
7) *Output analysis:* The obtained performance metrics are analyzed statistically and logically.
8) *Final recommendations:* The analyst formulates the final recommendations by using output analysis for the solving system's problem.

3.2 Types of Simulation Models

This section helps to answer the fourth research question (RQ4). This section defines different types of simulation models which have been defined in literature. By providing the different kind of simulation model, the present section helps to answer research question five and six (RQ5, RQ6) because it provides an idea about simulation approach and its types related to these questions.

There are various model classifications. One of them is summarized in Figure 8.

A model is designed to capture certain behavioral aspects of the modeled system (Altiok & Melamed, 2001). *Deterministic simulation model* is free of stochastic parameter. Providing an input set provides an output set. Since it is free of stochasticity, it provides the same results all the times (given that you provide the same input set). *Stochastic simulation model* includes at least one stochastic parameter, provides random output and forecasts characteristics of the system statistically (Banks, Carson II, Nelson, & Nicol, 1984).

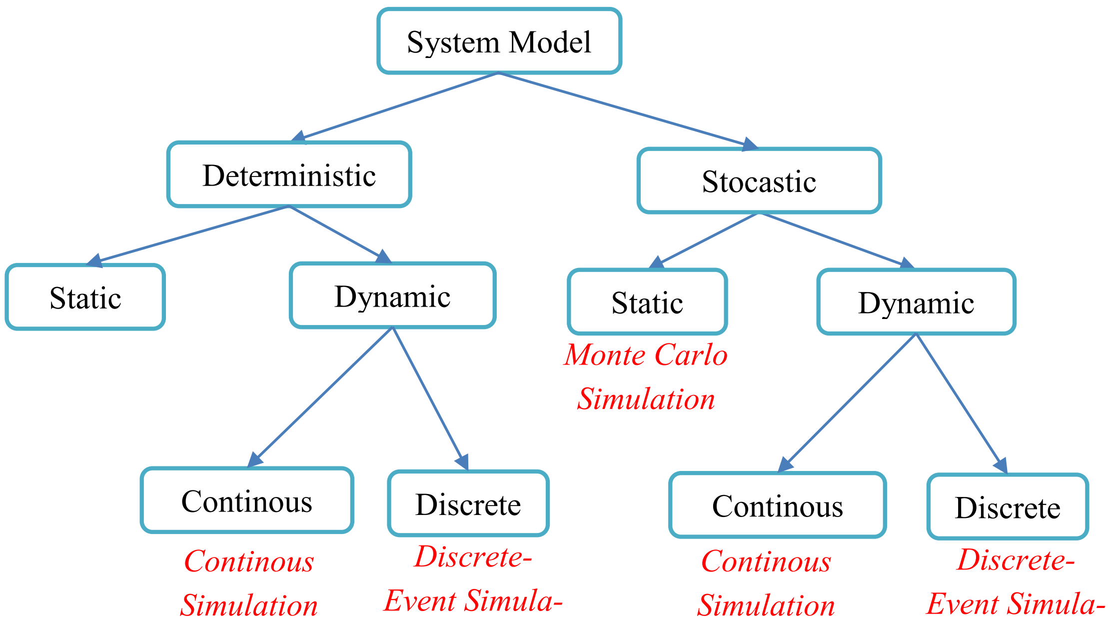

Figure 8. *Types of Simulation Models*

Static simulation models represent the state of the system at a certain time. A static simulation sometimes called Monte-Carlo Simulation technique is to withdrawn random numbers from a probability function to use in simulation. Monte Carlo Simulation is a simulation which uses random numbers. *Dynamic simulation models* represent the state of the system for a time period or the whole process time. This means it changes over time (Banks, Carson II, Nelson, & Nicol, 1984).

Discrete system which can be called Discrete Event system states variable(s) change only at a discrete set of points in time. Figure 9 shows changing of discrete system over time. *Continuous system* states variable(s) change continuously over time. Figure 9 shows changing of continuous system over time (Banks, Carson II, Nelson, & Nicol, 1984).

Discrete Event System Simulation is implemented by the majority of modern computer simulation tools (simulators). It provides so general and powerful implementation framework for most simulation languages (Altiok & Melamed, 2001). Discrete event simulation models are analyzed by numerical methods rather than by analytical methods (Banks, Carson II, Nelson, & Nicol, 1984).

Discrete event simulation is also a highly flexible tool that enables us to evaluate effects of different alternatives of system configurations and operating strategies to support decision making in the manufacturing context. Thus, Discrete event simulation used for analyzing and understanding the dynamics of manufacturing system is one of the most commonly techniques (Negahban & Simith, 2013).

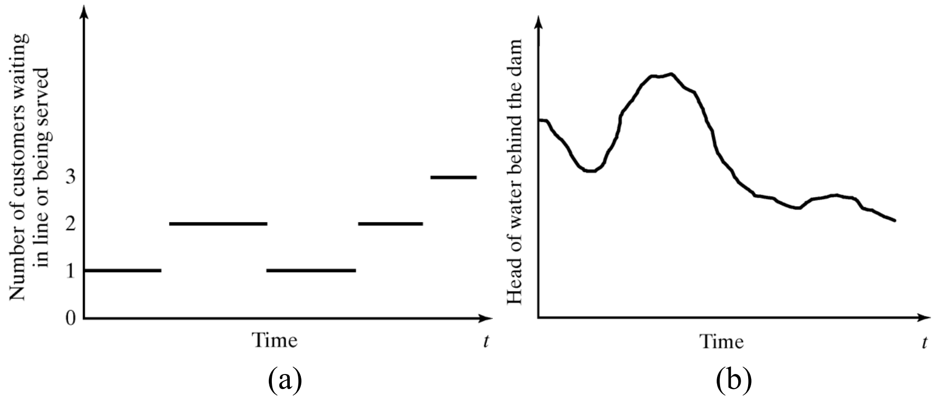

Figure 9. *(a) Discrete System and (b) Continuous System*

There are many tools/methodologies of discrete event system simulation in literature. For instance, simulation metamodeling, neural networks, genetic algorithms, simulated annealing, tabu search, regression, kriging method, response surface, data envelopment analysis. Some examples for emerging topics in recent years, robust analysis deadlock detection/prevention, decision support system, fuzzy theory, multi-agent systems (Negahban & Simith, 2013).

Another classification of simulation models which is stated by (Altiok & Melamed, 2001) is shown in Figure 10.

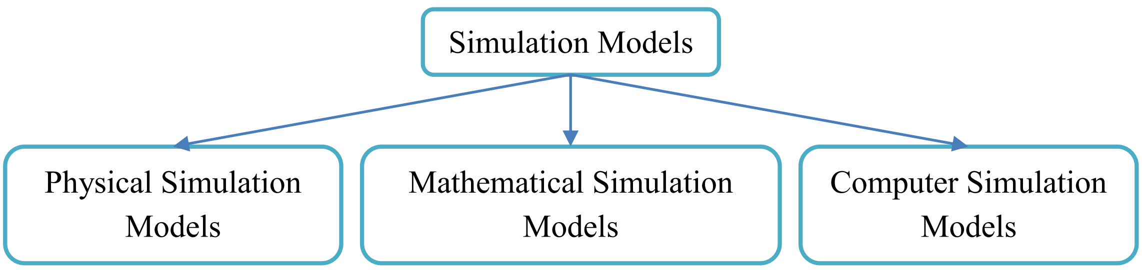

Figure 10. *Type of Simulation Models*

Shortly, a simplifies or scaled down physical object is a *physical simulation model*. For example, scale model of a car. A set of equations or relation among mathematical variables is an analytical or *mathematical simulation model*. For example, a set of equations describing the workflow on production line. *A computer simulation model* is only a program description of the system. For example, the operation of a manufacturing process over a period of time (Altiok & Melamed, 2001).

One of the most popular issue is recently the Digital Twin Approach. According to (Rodic, 2017) "Digital Twin Concept: Simulation is a core functionality of systems by means of seamless assistance along life cycle, e.g. supporting operation and service with direct linkage to operation data."

Digital twin called new simulation modeling paradigm extends the use of simulation modeling to all phases of the system life cycle (Rodic, 2017). (Schluse & Rossmann, 2016) shows "different dimensions when using simulation technology throughout the entire life cycle of a system" in Figure 11.

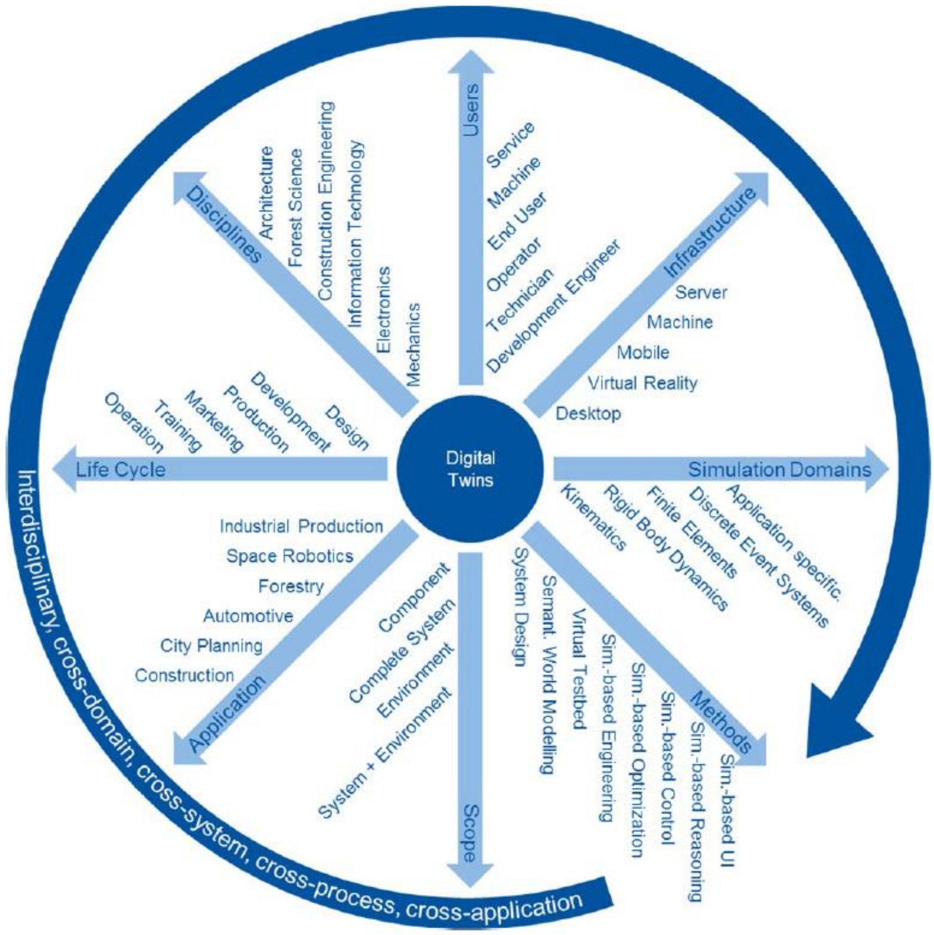

Figure 11. *Different dimensions when using simulation technology throughout the entire life cycle of a system*

3.3 Impact of Using Simulation in Internal Production Systems

There are many advantages of simulation, but there are also some disadvantages. Some advantages of simulation can be listed as follows (Banks, Carson II, Nelson, & Nicol, 1984);

- Simulation makes possible to compare alternative designs with each other.
- New strategy or processes can be tested and analyzed without disturbing ongoing operations of the real system.
- Complex real systems can be investigated analytically with simulation.
- You can observe how local changes in production system affect all production system.

Some disadvantages can be listed as follows (Banks, Carson II, Nelson, & Nicol, 1984);

- *Simulation modeling and analysis is time consuming.*
  Especially, collecting adequate data and fitting it a statistical distribution are time consuming parts of simulation approach.
- *Simulation modeling and analysis requires special training and experience.*
  Making a simulation needs special training and experience, because making a decision about a lot of criteria such as which data should be collected and used, how to build simulation models and which outputs is important, etc. should be realized by the people having special training and experience.
- *Simulation models compare alternative solutions instead of finding the best solution.*
  Simulation compares different solutions under different scenarios. It does not guarantee to find the best solution.
- *Simulation modeling and analysis needs special software.*

Using simulation approach is common for analyzing, designing and optimizing complex production systems. In addition to this, there are various reasons for widely using simulation approach in production systems (Altiok & Melamed, 2001);

- *Using of complex automation systems in order to satisfy fast and high quality production requirements*
  Representation of complex systems with mathematical methods is very difficult, sometimes it is impossible. For this reason, simulation statistically provides representation of complex systems in order to predict effect of changes in the system
- *High cost of equipment and facilities*
  Especially implementation of Industry 4.0 technologies (or equipment) can be very expensive, so simulation is very important in order to predict effects

of these technologies to production systems before implementing them to real system.

- *Variability of production systems: human factor*
  Production systems consist of many variables. Forecasting and evaluating the system performance is very difficult because of these variables. Simulation allows to do this, statistically.
- *Developing simulation software and faster computers*

4. LITERATURE REVIEW

4.1 Literature Review Methodology

The literature review part of this study try to answer research questions (RQ5 and RQ6) by applying a systematic literature methodology. In this section, the systematic literature review methodology, the databases used in the review, key words and practical screening criteria are presented to review the literature related to our research gap. Process model of (Fink, 2014) was applied for systematic literature review. The process model consists of seven steps:

1) Selecting research questions,
2) Selecting bibliographic or article database, web sites, and other sources,
3) Choosing search terms,
4) Applying practical screening criteria,
5) Applying methodological screening criteria,
6) Doing the review,
7) Synthesizing the results.

The research questions were precisely stated at the previous sections in the study for guiding the literature review. Later, the suitable databases were selected. The following three databases that is large, interdisciplinary and popular were used in order to ensure a comprehensive sample that covered the most important data related to our study. These databases are:

- Web of Science,
- Scopus,
- Science Direct.

These databases were considered to cover different types of major journals on simulation, Industry 4.0 and production systems.

Thirdly, three groups of search terms were defined to obtain the most appropriate papers related to issues of our research area. These three groups of search terms are:

- “simulation” and “industry 4.0”
- “simulation” and “industrial internet”
- “simulation” and “smart factory"

To translate these groups of search terms into search strings, key words were defined as “simulation”, “industry 4.0”, “industrial internet” and “smart factory”.

Fourthly, in order to screen the literature and get the relevant articles, practical screening criteria were determined for inclusion into and exclusion from the review. The practical screening criteria consist of factors for example, article's language, type of paper (journal paper, conference proceed…). Only papers that matched the practical screening criteria were included in the review. The article's objectives and implications must provide the inclusion criteria. Papers that focused on physical simulation model were excluded (Physical simulation model was defined in Types of Simulation part in this study). We also excluded duplicates and no full access articles. Only studies being in English and journal paper were included in the review. Our all practical screening criteria was shown in Table 1.

Table 1. *Practical Screening Criteria*

Inclusion Criteria	**Type**
Include only studies in English	Publication language
Include studies focused on simulation, industry 4.0, industrial internet and smart factory	Content
Include studies focused on manufacturing, production or management perspective	Content
Include only journal papers	Setting
Include studies having accessible full text	Setting
Include Discrete Event System Simulation and Simulation Game studies	Content

Exclusion Criteria	**Type**
Exclude Physical Simulation studies	Content
Exclude papers having no full access	Setting
Exclude duplicates	Content

Remaining part of systematic literature review process model (applying practical screening criteria and methodological screening criteria, doing the review and synthesizing the results) will be applied and stated next sections of the study.

4.2 Practical and Methodological Screening

In this section, the practical screening criteria outlined in Table 1 and methodological screening were applied to the papers that was obtained from the three databases and results were stated.

A total of 95 articles were obtained from the three databases (Web of Science, Scopus, Science Direct) by searching the search terms and the keywords that mentioned in previous section on the titles, abstract and keywords of the papers. Then only studies that matched the inclusion criteria were included in the study. 65 articles of the 95 obtained articles were excluded from the study, because they were inappropriate to the inclusion criteria. 30 included articles proceeded to the next step, methodological screening.

Methodological screening criteria were applied as follows:

- The papers which describe and apply simulation to a sample system (The papers including not only conceptual or theoretical part but also empirical part) were included in the study to answer the research questions.
- The papers which Industry 4.0 and its technologies are main point and centre were included in the study.

In total, 9 papers (Conceptual papers (two) and papers being inappropriate to our research targets (seven)) were excluded during the methodological screening of articles. As a result, 21 articles were found appropriate in order to proceed to next steps of the study. These articles are shown in Table 2.

Table 2. *Obtained Papers After Practical and Methodological Screening*

Title	Published by	Year
Digital factory technologies for robotic automation and enhanced manufacturing cell design	Cogent Engineering	2018
Innovative production scheduling with customer satisfaction based measurement for the sustainability of manufacturing firms	Sustainability — Open Access Journal	2017
Industrial big data-based scheduling modeling framework for complex manufacturing system	Advances in Mechanical Engineering (AIME) - Open Access Journal	2017
Industry 4.0 and the new simulation modelling paradigm	Organizacija - Journal of Management, Informatics and Human Resources	2017
Equipment utilization enhancement in photolithography area through a dynamic system control using multi-fidelity simulation optimization with big data technique	IEEE Transactions on Semiconductor Manufacturing	2017
Potential connections of unique manufacturing and industry 4.0	Logforum-Scientific Journal of Logistics	2017
A digital twin-based approach for designing and multi-objective optimization of hollow glass production line	IEEE Access® - Open Access (OA), Applications-Oriented, All-Electronic Archival Journal	2017
Simulation model study for manufacturing effectiveness evaluation in crowdsourced manufacturing	Cirp Annals - Manufacturing Technology – Elsevier	2017

A new method for autonomous control of complex job shops - Integrating order release, sequencing and capacity control to meet due dates	Journal of Manufacturing Systems	2016
Discrete event simulation and virtual reality use in industry: new opportunities and future trends	IEEE Transactions on Human-Machine Systems	2016
Simulation optimization in the era of Industrial 4.0 and the Industrial Internet	Journal of Simulation	2016
Towards smart factory for industry 4.0: a self-organized multi-agent system with big data based feedback and coordination	Computer Networks	2016
Future modeling and simulation of cps-based factories: an example from the automotive industry	IFAC Papersonline - Elsevier	2016
Smart solution for smart factory	IFAC Papersonline - Elsevier	2016
Two-objective stochastic flow-shop scheduling with deteriorating and learning effect in Industry 4.0-based manufacturing system	Applied Soft Computing	2017
Simulation based validation of supply chain effects through ICT enabled real-time-capability in ETO production planning	Procedia Manufacturing - Elsevier	2017
Interactive design of reconfigurable logistics systems	Procedia Engineering - Elsevier	2017
Portable rapid visual workflow simulation tool for human robot coproduction	Procedia Manufacturing - Elsevier	2017
Developing performance measurement system for Internet of Things and smart factory environment	International Journal of Production Research	2016
Simulation game for intelligent production logistics – The PuLL® Learning Factory	Procedia CIRP 54 – Elsevier	2016
Bayesian inference for mining semiconductor manufacturing big data for yield enhancement and smart production to empower industry 4.0	Applied Soft Computing	2017

4.3 Review and Qualitative Analysis

In this section, The sixth step of literature review process model of (Fink, 2014), review and qualitative analysis, was done. In consequence of review and qualitative analysis, a general overview of the reviewed articles is shown in Table 3.

Table 3. *A General Overview of the Reviewed Articles*

Author(s)	Main Research Goal
(Caggiano & Teti, 2018)	To increase performance of the upgraded manufacturing cell in terms of resource utilization and throughput time.
(Shim, Park, & Choi, 2017)	To define innovative production scheduling using big data, cyber-physical systems, internet of things, cloud computing, mobile network, and so on.
(Zhu, Qiao, & Cao, 2017)	To define and evaluate the industrial big data based scheduling modelling framework for complex manufacturing systems.

(Rodic, 2017)	To introduce the Industry 4.0 paradigm, present its background, current state of development and state its influence on the development of the simulation modelling paradigm.
(Hsieh, 2017)	To maximize the equipment utilization by an efficient multi-model simulation optimization approach with big data techniques in the era of Industry 4.0.
(Kocsi & Olah, 2017)	To optimise production processes with machines connected to each other via intelligent communication systems and achieve more reliable processes with shorter production time and lower production costs.
(Zhang, Lıu, Chen, Zhang, & Leng, 2017)	To present a digital twin based approach for rapid individualized designing of the production line.
(Kaihara, Katsumura, Suginishi, & Kadar, 2017)	To develop a simulation model of crowdsourced manufacturing and evaluate manufacturing effectiveness based on delivery and machine usage
(Grundstein, Freitag, & Scholz-Riter, 2016)	To present the autonomous production control method, Which integrates all control tasks (sequencing, release and capacity control) to meet due dates.
(Tuner, Hutabarat, Oyekan, & Tiwari, 2016)	To combine discrete event simulation (DES) and virtual reality (VR) use within industry for fully meeting the visualization requirements of both Industry 4.0 and Industrial Internet visions of digital manufacturing..
(Xu *et al.*, 2016)	To explore potential of simulation optimization and use simulation optimization as a decision making tool
(Wang, Wan, Zhang, Li, & Zhang, 2016)	To design distributed self-decision making and intelligent negotiation mechanisms for optimizing system performance.
(Weyer, Meyer, Ohmer, Gorecky, & Zühlke, 2016)	To deal with upcoming challenges to exploit the full potential of modelling and simulation within Smart Factory
(Hajrizi, 2016)	To present the integrative approach for modelling, simulation, control and optimization to create a smart solution for complex systems
(Fu, Ding, Wang, & Wang, 2017)	To investigate a flow-shop scheduling problem under the consideration of multiple objectives, uncertainty and time dependent processing time
(Dallasega, Rojas, Raunch, & Matt, 2017)	To present an Information and Communication Technology (ICT)-supported nearly real-time capable production planning approach.
(Furmann, Furmannova, & Wiecek, 2017)	To describe a methodology of interconnection of the real logistic elements with interactive projection planning system and process simulation and reflect the demands of reconfigurable logistic systems design.
(Dukalski, Çençen, Aschenbrenner, & Verlinden, 2017)	To describe the Workflow Simulation Tool which is part of the Human-Robot Coproduction Methodology, currently in development.
(Hwang, Lee, Park, & Chang, 2016)	To develop an Internet of Things (IoT)-based production performance measurement system and investigate the effect of the IoT-workability on the Overall Equipment Effectiveness (OEE).
(Blöchl & Schneider, 2016)	To develop a new simulation game for teaching the application of Industry 4.0 technologies in internal material flow.

(Khakifirooz, Chien, & Chen, 2017)	To develop a framework to investigate the manufacturing data for fault detection to empower intelligent manufacturing.

Table 3 is useful for understanding relationship of the papers with production system and it also proves a general opinion about the purpose of the papers.

In the review process, type of simulation using in the papers was also investigated to state relationship of the papers with simulation. Type of simulation used in the papers shown in Table 4.

Table 4. *Type of simulation using in the papers*

Author(s)	Type of Simulation
(Caggiano & Teti, 2018)	3D Motion Simulation and Discrete Event Simulation were jointly used.
(Shim, Park, & Choi, 2017)	Discrete Event Simulation
(Zhu, Qiao, & Cao, 2017)	Discrete Event Simulation
(Rodic, 2017)	Digital Twin based Simulation
(Hsieh, 2017)	Discrete Event Simulation
(Kocsi & Olah, 2017)	Monte Carlo bases process simulation
(Zhang, Lıu, Chen, Zhang, & Leng, 2017)	Digital Twin and Distributed Semi-Physical Simulation
(Kaihara, Katsumura, Suginishi, & Kadar, 2017)	Supervised agent based simulation
(Grundstein, Freitag, & Scholz-Riter, 2016)	Discrete Event Simulation
(Tuner, Hutabarat, Oyekan, & Tiwari, 2016)	Discrete Event Simulation
(Xu *et al.*, 2016)	Discrete Event Simulation
(Wang, Wan, Zhang, Li, & Zhang, 2016)	Agent based simulation
(Weyer, Meyer, Ohmer, Gorecky, & Zühlke, 2016)	Digital twin and Multi-disciplinary simulation (Discrete Event Simulation, Supply chain simulation, Production planning simulation…)
(Hajrizi, 2016)	Discrete Event Simulation
(Fu, Ding, Wang, & Wang, 2017)	Monte Carlo Simulation
(Dallasega, Rojas, Raunch, & Matt, 2017)	Discrete Event Simulation
(Furmann, Furmannova, & Wiecek, 2017)	Digital twin and dynamic simulation with genetic algorithm
(Dukalski, Çençen, Aschenbrenner, & Verlinden, 2017)	Discrete Event Simulation
(Hwang, Lee, Park, & Chang, 2016)	Virtual factory simulation
(Blöchl & Schneider, 2016)	Simulation game
(Khakifirooz, Chien, & Chen, 2017)	New simulation model

Table 4 also provides awareness about types of simulation used for implementation of Industry 4.0 technologies and states relationship of the papers with simulation.

In order to analyse the articles, we defined three questions and created Table 5 to answer these questions. In the first question, we tried to determine the problems discussed in the papers and related to Industry 4.0 implementation. Then, in the second question, we tried to state how simulation aid to solve the problem in the papers. Lastly, in the third question, we tried to state benefits of simulation obtained from the papers. You can see our three analysis questions as follows;

1) Which problems related to Industry 4.0 implementation were focused by simulation?
2) How were the problems addressed by simulation?
3) Which type of benefits of simulation were noticed?

Table 5. *Analysis of the papers according to the questions*

Author(s)	(1)	(2)	(3)
(Caggiano & Teti, 2018)	Increasing performance of the upgraded manufacturing cell in terms of resource utilization and throughput time.	Simulation was employed for the modelling and simulation of different cell settings for proper layout configuration, safe motion planning and resource utilization improvement.	Simulation helps to define the best strategy for the physical manufacturing system and carry out effectively decision-making.
(Shim, Park, & Choi, 2017)	Scheduling problem	Simulation was used for validation and performance evaluation of the proposed scheduling algorithm.	Simulation helps decision making and evaluation of proposed algorithms.
(Zhu, Qiao, & Cao, 2017)	Scheduling problem	Simulation analyzes proposed scheduling strategy performance by representing the real system.	Simulation helps performance evaluation, compare and select the best plan.
(Rodic, 2017)	Adoption of new technologies	The new simulation framework and approach were stated to solve adoption problems.	Simulation helps to solve adoption problems by representing new system in digital environment.
(Hsieh, 2017)	Maximizing the equipment utilization	Simulation optimization approach with big data technique maximizes equipment utilization by using (near)-real time data.	Simulation and simulation optimization approaches help to improve equipment utilization.
(Kocsi & Olah, 2017)	Optimising production processes and	Process simulation was used to examine cost of the process	Simulation helps to predict some perfor-

	achieving more reliable processes with shorter production time and lower production costs.	and the total production time.	mance metrics of proposed system without changing real system.
(Zhang, Lıu, Chen, Zhang, & Leng, 2017)	Designing of the production line	Simulation merges physics based system modelling and distributed (near) real time process data to generate digital design of the system at preproduction phase.	Simulation provides engineering analysis capabilities and support decision making over solution evaluation and the system designing.
(Kaihara, Katsumura, Suginishi, & Kadar, 2017)	Evaluating manufacturing effectiveness	The agent based manufacturing simulation model with future production plans was presented to estimate effectiveness of the crowdsourced manufacturing.	Simulation with proposed algorithms can be used evaluating current effectiveness of manufacturing systems.
(Grundstein, Freitag, & Scholz-Riter, 2016)	Production control method which integrates all control tasks (sequencing, release and capacity control) to meet due dates.	The stated production control method was benchmarked with established method combinations using simulation.	Simulation helps to prove proposed systems/methods without implementing them in real system.
(Tuner, Hutabarat, Oyekan, & Tiwari, 2016)	The visualization requirements of both Industry 4.0 and Industrial Internet visions of digital manufacturing.	The paper tries to fully meet the visualization requirements with combining simulation and virtual reality (VR-based simulation system).	Integration of simulation and Industry 4.0 technologies helps factory design and layout, product and service development, and industrial plant decision making and control.
(Xu *et al.*, 2016)	Decision making tool	Simulation optimization was stated as a decision making tool and smart brain.	Simulation optimization provides drastically improvement the efficiency of industrial systems.
(Wang, Wan, Zhang, Li, & Zhang, 2016)	Optimization of system performance	Simulation was used to assess and improve the effectiveness of the proposed optimization mechanism and strategies.	Simulation is used to verify the proposed framework, its mechanism and strategies and helps development of proposed framework.

(Weyer, Meyer, Ohmer, Gorecky, & Zühlke, 2016)	Optimization and acceleration of all phases of the production life-cycle Evaluation of the impact of external and internal changes	A framework with multidisciplinary co-simulation concept was stated to eliminate the problems.	Simulation gives chance to evaluate impact of changes without modifying real-system.
(Hajrizi, 2016)	Optimization, planning and control of production systems	A simulation of the investigated manufacturing systems that consists of several output, input, analysing and communication modules was proposed.	Simulation consisting of intelligent modules can provide a high-quality scheduling, system control and dynamic planning.
(Fu, Ding, Wang, & Wang, 2017)	Scheduling problem	Simulation experiments on a set of test problems was designed to evaluate proposed algorithm.	Simulation helps performance evaluation of algorithm proposed to eliminate problems.
(Dallasega, Rojas, Raunch, & Matt, 2017)	Production planning	Simulation was used to validate the effects of the proposed nearly real time production planning approach.	Simulation helps to validate proposed approaches, before implement it in real system.
(Furmann, Furmannova, & Wiecek, 2017)	Interconnection of the real logistic elements and planning logistic systems	The problems were eliminated with mentioned projection planning system and by connecting the dynamic simulation with real logistics systems through intelligent sensors.	Simulation provides representation of real system as synchronous with digital world through sensors. This makes it more useful to evaluate new solution.
(Dukalski, Çençen, Aschenbrenner, & Verlinden, 2017)	human – robot coproduction	Simulation tool which part of Human Robot Coproduction Methodology was developed. This solution consolidates visual components and structure sensor within handheld portable system.	Simulation helps to improve the efficiency of human-robot coproduction with appropriate and fast modelling solution.
(Hwang, Lee, Park, & Chang, 2016)	Performance measurement for internet of things and smart factory environment	Simulation was used for validation of the proposed model to develop performance	Simulation helps to validate proposed model, before implement it in real system.

		measurement system.	
(Blöchl & Schneider, 2016)	Training of workers	Simulation game was developed to teach production logistics planners what Lean and Industry 4.0 means in the context of production logistics and how they can use Industry 4.0 technologies.	Simulation helps to train workers to correctly use and implement new technologies in real system.
(Khakifirooz, Chien, & Chen, 2017)	Big data analysis	Simulation was used to validate the proposed approach for analysing big data.	Simulation helps to validate proposed big data analysis approaches.

Table 5 is useful to see the possibilities of simulation for Industry 4.0 implementation, how simulation addresses the problems, and answer the fifth and sixth research questions.

4.4 Results of the Analysis

In this part, we obtained the results from the literature review and qualitative analysis part. The Number of articles by year and the number of simulation types using in the literature were presented in two different charts. We also stated the benefits of simulation approach used in the papers and what kind of possibilities the simulations provide by using output of the review and qualitative analysis part.

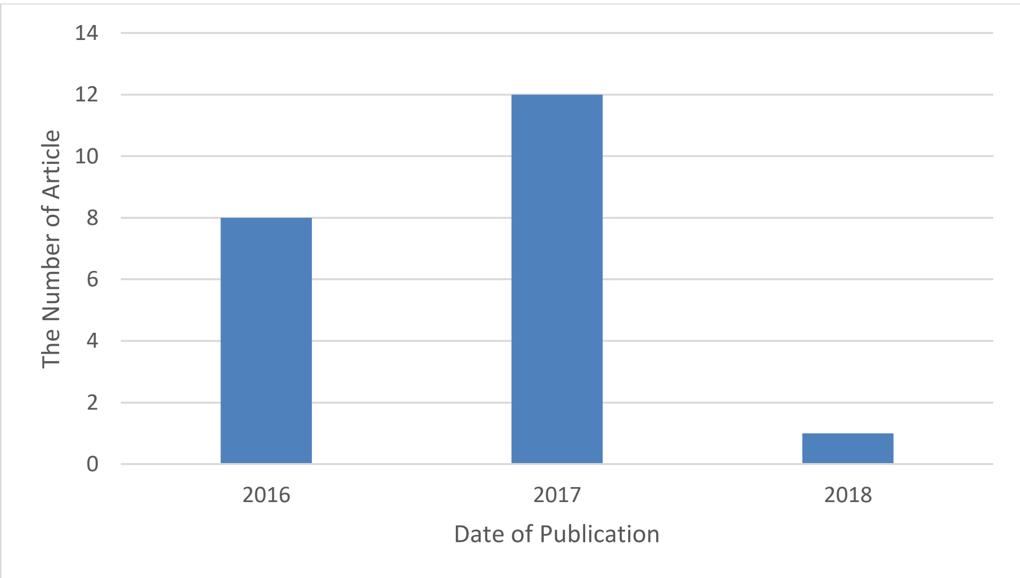

Figure 12. *Number of the articles by year*

All of the papers obtained after practical and methodological screening were published in 2016, 2017 and 2018. The Number of the articles by year is shown in Figure 12. Figure 12 means that simulation for production systems in implementation of Industry 4.0 is still a young research area. So, this research area can give lots of opportunities for future research.

The number of simulation type using in the articles was shown in Figure 13 which was obtained from Table 4. As it can be seen, Discrete Event Simulation was mostly preferred by the author(s).

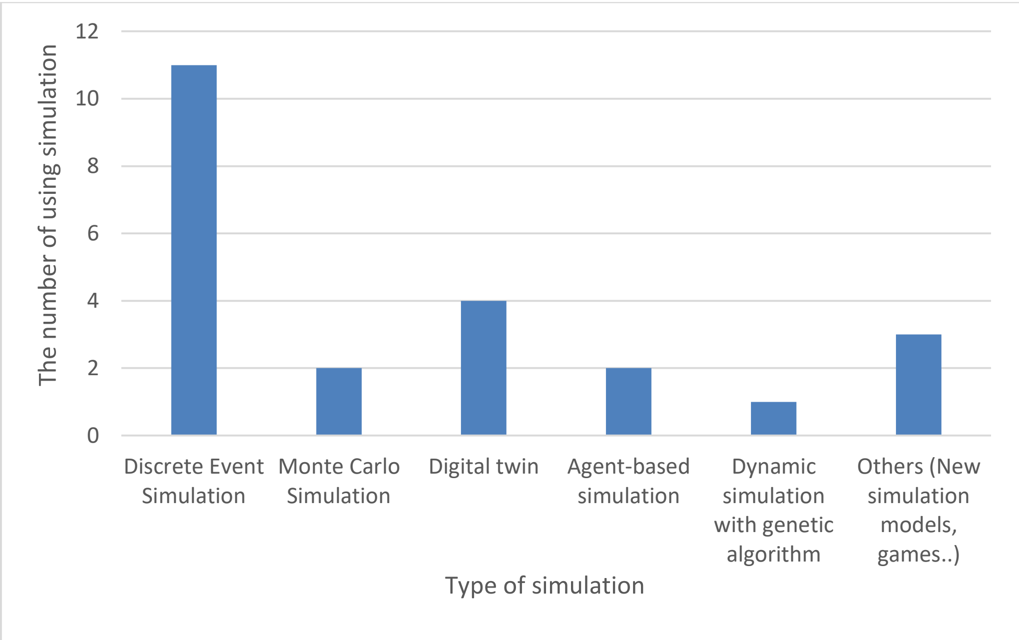

Figure 13. *Number of simulation type using in the literature*

Digital twin was presented as the new simulation modelling paradigm in Industry 4.0 era by (Rodic, 2017). In the Figure 13, you can see that digital twin is the second simulation modelling approach of the most used in the literature, even though it is still new paradigm and research area.

According to Table 5, we summarized the problems related to Industry 4.0 implementations in Table 6. We also stated the number of references mentioning same problems. Obviously, increasing / optimizing the performance of manufacturing process or the equipment utilization is common problem discussed by the papers. This problem can also be included in organizational and production fit challenge of Industry 4.0.

Table 6. *Problems stated in the papers*

Problem	Number of references	List of related references
Increasing / optimizing the performance of manufacturing process / equipment utilization	6	(Caggiano & Teti, 2018) (Hsieh, 2017) (Kocsi & Olah, 2017) (Wang, Wan, Zhang, Li, & Zhang, 2016) (Weyer, Meyer, Ohmer, Gorecky, & Zühlke, 2016) (Hajrizi, 2016)
Scheduling	3	(Shim, Park, & Choi, 2017) (Zhu, Qiao, & Cao, 2017) (Fu, Ding, Wang, & Wang, 2017)
Adoption of the technologies	1	(Rodic, 2017)
Designing of the production line	1	(Zhang, Lıu, Chen, Zhang, & Leng, 2017)
Evaluating manufacturing effectiveness / Performance measurement for smart factory	2	(Kaihara, Katsumura, Suginishi, & Kadar, 2017) (Hwang, Lee, Park, & Chang, 2016)
Production control / planning	2	(Grundstein, Freitag, & Scholz-Riter, 2016) (Dallasega, Rojas, Raunch, & Matt, 2017)
The visualization requirements	1	(Tuner, Hutabarat, Oyekan, & Tiwari, 2016)
Decision making tool	1	(Xu *et al*., 2016)
Planning logistic systems	1	(Furmann, Furmannova, & Wiecek, 2017)
Human – robot coproduction	1	(Dukalski, Çençen, Aschenbrenner, & Verlinden, 2017)
Training of workers	1	(Blöchl & Schneider, 2016)
Big Data analysis	1	(Khakifirooz, Chien, & Chen, 2017)

According to Table 6, the second most common problem is the scheduling problem. It can also be included in organizational and production fit challenges of Industry 4.0.

In the papers, simulation helps to eliminate a lot of problems (see Table 6) related to Industry 4.0 implementation.

One of the problems is that increasing / optimizing the performance of manufacturing process or the equipment utilization. Simulation helps to define the best strategy for a manufacturing system and carry out effectively decision-making by modelling and simulating of different cell/machine settings in order to increasing / optimizing the performance of manufacturing process or the equipment utilization.

Scheduling is the second common problem handled by the papers. Simulation helps decision making and evaluation of proposed algorithms in order to solve scheduling problem. Simulation also helps performance evaluation, compare and select the best plan for scheduling.

Adoption of new technologies is another problem for Industry 4.0 implementation in the articles. Simulation helps to solve adoption problems by representing new system in digital environment. Some new simulation approach and framework were improved to solve adoption problems (Rodic, 2017).

Simulation provides engineering analysis capabilities and support decision making over solution evaluation and the system designing. This benefit of simulation helps to remove the problem related to designing of production line implementing Industry 4.0.

Simulation with proposed algorithms helps to solve evaluating manufacturing effectiveness and performance measurement problem for smart factory by validating proposed model, before implement it in real system. Also, simulation helps another problem, production planning and control, in the production systems implemented Industry 4.0 with validating the effects of the proposed nearly real time production planning and control approach, before implement it in real system. Thus we can avoid extra cost by using simulation for evaluating manufacturing effectiveness and production plans.

The visualization requirements in the production system for implementing Industry 4.0 is another problem in the articles. Integration of simulation and some technologies (e.g. virtual reality) meet the visualization requirements and helps factory design and layout, product and service development, and industrial plant decision making and control for implementing Industry 4.0.

Another issue in the Industry 4.0 implementation is human – robot coproduction improvement. Simulation helps to improve the efficiency of human-robot coproduction with appropriate and fast modelling solutions. That is the another benefit of using simulation approach for implementing Industry 4.0 in the production system.

Training of workers is a problem for implementing Industry 4.0. The problem can be removed with simulation game. Simulation game consists of combination of simulation approach and game application. It is developed to teach workers new concepts and technologies. The simulation game helps to train workers to correctly use and implement new technologies in real system. Thus, simulation provides an opportunity for training of workers to implement Industry 4.0 concept.

Big Data analysis is a problem mentioned by the papers for implementing Industry 4.0. Collected data by Industry 4.0 technologies (e.g. sensors, wireless…) in production system must be analyzed to improve the system efficiency. Simulation helps to improve the big data analysis approach and validate proposed big data analysis approaches.

As a result, simulation is a useful approach to solve Industry 4.0 implementation problems in production system according the literature. It provides a lot of possibilities for implementing Industry 4.0 technologies.

5. DISCUSSION AND CONCLUSIONS

Once the literature has been analysed and the results of the literature review have been presented in previous section, now we can move to the relevance of these results in the context of this report. In this section, each research question already presented in the first section is separately discussed and an answer to the overall research question is stated as a summary of all the content of this report. To conclude the chapter, limitation of this report and future research areas are briefly discussed.

5.1 Discussion

Moving back to the first section of this report, the research gap for this study was presented as well as the overall research question and the sub-research questions. In the following section, the research questions will be answered one by one through a discussion of the previous parts of the reports.

RQ1. What are the Industry 4.0 technologies in internal production systems/processes?

This question was related to one of the most basic concepts concerning to the topic. Firstly, section 2.1 presented Industry 4.0 concept definition, its background and benefits, and building blocks of Industry 4.0 in order to understand the next section. The German term Industry 4.0 means the fourth industrial revolution. Evaluation of Industry 4.0 and the other three industrial revelation is shown Figure 3.

Industry 4.0 is only a concept, what is the behind it is the related technologies that make it possible in internal production systems/processes. This information presented in section 2.2 including basic technologies definition related to Industry 4.0 in internal production system. Industry 4.0 involves the implementation of these technologies which are important for the Smart Factory. According to this section, we stated main Industry 4.0 technologies shortly in Table 7.

Table 7. *Industry 4.0 Technologies*

Technology	Definition
Wireless sensor networks (WSN)	Multiple sensors (sensor nodes) are wirelessly used together and interact communicating between them so, they are called wireless sensor network (WSN).
Actuators	Actuators are components of automated systems driving movement and change.

Radio Frequency Identification (RFID)	RFID includes electronic information that can be communicated wirelessly via electromagnetic fields.
Middleware	Middleware connects the Industrial Internet hardware generating huge amounts of data such as actuators, sensors, etc. with applications making use of this data for further analysis.
Big data and advanced analytics	Large (from terabytes to exabytes), complex (from sensor to social media) structured amounts of data which traditional databases and processing tools cannot manage is called as Big Data.
Cloud computing	Cloud service provides storage and processing of the huge amount of data for manufacturing systems.
Augmented Reality	Augmented reality based systems reduce the costs by enhancing training and maintenance procedures of manufacturers.
Simulation and virtualization	In order to create digital twins used for simulation modeling and testing, Industry 4.0 uses virtualization.
Additive Manufacturing (3-D Printing)	Additive manufacturing (e.g. 3D printing) facilitate the manufacturing and design of the products according to the customer expectations.

These Industry 4.0 technologies bring not only many benefits but also many challenges, together. We tried to present what these challenges are in the next research question.

RQ2. What kind of challenges are there for implementing Industry 4.0 technologies in case of internal production systems/processes?

After Industry 4.0 concept and its technologies were presented, we tried to state the challenges mentioned in literature for implementing Industry 4.0 technologies in the section 2.3. We presented these challenges under the main topics in the section 2.3. These topics are;

- Competitiveness and future viability
- Organizational and production fit
- Employee qualifications and acceptance
- Technical challenges;
    - Intelligent decision making and negotiation mechanism,
    - High speed industrial wireless network (IWN) protocols,
    - Manufacturing specific big data and its analytics,
    - System modeling and analysis,

- Cyber and property security,
- Modularized and flexible artifacts.

Industry 4.0 takes place in a highly dynamic competitive environment. Furthermore, Industry 4.0 creates completely new and different industries, reshapes industry boundaries and exposes established manufacturing companies to new competitive challenges. Facilitated market entrance of new competitors and increasingly competitive dynamics are among the most important challenges in the Industry 4.0 era.

The implementation of Industry 4.0 has to be specifically planed for changing production and organizational scenario, such as regarding company size or different production structures.

In order to approach the new concepts and Industry 4.0 technologies, employees need to be qualified. Furthermore, businesses should have the employees having these qualifications; willingness to learn, creative problem solving in social settings, understanding network technologies as well as data analysis and processing and ability to find practical solution. Developing these qualifications is a challenge for manufacturers.

Industry 4.0 implementation needs technical applications, but these applications bring along many other challenges. For example, the huge amount of data are collected by wireless sensor network technology but the main questions that should be answered are that which data should be collected, how these data can be collected, how to analyze the data and what is the meaning of the data.

In order to eliminate these challenges and increase the benefits of Industry 4.0 implementation, simulation modeling of a system is a one of key approaches using in literature for decision making and provides many other possibilities.

RQ3. Why is simulation required and Where can simulation be used in overall?

This question was related to another the most basic concepts concerning to the topic. In order to answer the main question, we should understand the simulation approach, application areas and impacts in the production system. Simulation approach, its application areas and impacts in the production system were presented in section 3.1 and section 3.3.

Simulation is one of the technological trends being the building blocks of Industry 4.0. It plays major roles in the optimization of production systems. Simulation not only is used in the optimization of production systems but also allows to improve and evaluate new technologies, algorithms, methods and designs.

Understanding the impact of new technologies/algorithms/methods/designs to the system by trial and error can be very costly. Simulation provides this without changing the real system.

For example, (Khakifirooz, Chien, & Chen, 2017) use simulation approach in order to evaluate and improve the proposed big data analysis framework in order to solve big data analytics challenge of Industry 4.0.

Simulation helps to adoption of new technologies. Adoption of new technologies is another problem in production systems. (Rodic, 2017) use the new simulation modelling paradigm and framework to eliminate adoption problem.

Simulation also can be used for training employees. It can provide cost efficient and safe application and training area for workers. For example (Blöchl & Schneider, 2016) used simulation within game application to train employees.

RQ4. What kind of different simulation methods are there in overall?

There are many types of simulation using in literature and researches. In order to understand the simulation approach using in the literature more detailed, types of simulation were presented in the section 3.2. One of the classification of simulation models is presented Figure 8.

Simulation models is divided into two different models; deterministic simulation models and stochastic simulation models. Deterministic simulation model is free of stochastic parameter. Stochastic simulation model includes at least one stochastic parameter, provides random output and forecasts characteristics of the system statistically.

These two models are also divided into two different models; static simulation models and dynamic simulation models. Static simulation models represent the state of the system at a certain time. A static simulation sometimes called Monte-Carlo Simulation technique is to withdrawn random numbers from a probability function to use in simulation. Dynamic simulation models represent the state of the system for a time period or the whole process time. This means it changes over time.

These two simulation models also consist of two different simulation models; discrete simulation models and continuous simulation models. Discrete system simulation model which can be called Discrete Event Simulation states variable(s) change only at a discrete set of points in time. Continuous system states variable(s) change continuously over time.

This simulation types can be used to eliminate challenges for implementation of Industry 4.0 technologies. Especially, Discrete Event Simulation is commonly used in the papers included in the literature review and analysis of this study (see Table 4).

(Hsieh, 2017) stated some reasons why Discrete Event Simulation was preferred for representing systems, such as analyzing complex stochastic systems becomes possible, because of the flexibility in the modelling of Discrete Event Simulation; Discreet Event Simulation can consider almost every detail in modelling as powerful tool for capturing the system behavior; in modern decision making, Discrete Event Simulation has become an important analysis and evaluation tool.

(Fu, Ding, Wang, & Wang, 2017) stated some reasons why Monte-Carlo Simulation was preferred for representing their system, such as if the number of replications tends to be infinite, Monte Carlo Simulation is an effective tool to approximate to the correct objective value; Monte Carlo Simulation has been utilized as a basic method to deal with lots of stochastic optimization problems, because it is easy and simple implementation.

RQ5. How do certain types of simulation that we focus on help to respond to the challenges of Industry 4.0 of internal production systems/processes?

We answer this question in the section 4.3 by analysing the literature. According to this section, we can summarize how simulation helps to respond the challenges as follows,

- Simulation approach increases / optimizes the performance of manufacturing process or the equipment utilization by modelling and simulating of different cell/machine settings.
- Simulation also compares plans under different scenarios.
- Simulation represents new system in digital environment to solve problems.
- Simulation validate proposed models / algorithms / methods and test them under different conditions.
- Simulation integrates other technologies in order to meet some requirement in production systems.
- Simulation is combined with game applications to solve training problems of employees.

(Caggiano & Teti, 2018) used Discrete Event Simulation and 3D Motion Simulation jointly. Discrete Event Simulation was used for upgraded manufacturing cell performance optimization and analysis and also, it allowed to examine different settings of the manufacturing cell to improve specified performance measures in this study by representing a valuable tool through which it is possible to analyse and study different what-if scenarios with limited computational effort in a digital framework.

Big data analytics was already stated as a challenge of Industry 4.0 implementation. In order to eliminate this challenge, (Khakifirooz, Chien, & Chen, 2017) proposed the big data analytics approach and used simulation for evaluating and validating this proposed big data analytics approach in the study.

(Tuner, Hutabarat, Oyekan, & Tiwari, 2016) tried to fully meet the visualization requirements of Industry 4.0 with combining simulation (Discrete Event Simulation) and virtual reality (VR-based simulation system). This combination makes it easier to view effects of complex data sets. It is capable of integration with other factory based systems. Thus, it helps to enable organizational and production fit which is one of the Industry 4.0 implementation challenges.

(Blöchl & Schneider, 2016) developed a game combined with simulation in order to meet training needs of employees which is another challenge for implementation of Industry 4.0. In order to approach the new concepts and Industry 4.0 technologies, employees need to be qualified.

RQ6. What are the benefits of simulation approaches for implementing Industry 4.0 technologies in internal production systems/processes?

We stated the benefits of simulation in the section 4.4 by using the previous sections of the report. All of these benefits aid to eliminate problems of Industry 4.0 implementation in production systems. According to the section 4.4, the benefits of simulation for implementing Industry 4.0 can be stated as follows,

- Simulation provides engineering analysis capabilities and support decision making over solution evaluation and the system designing.
- Simulation helps performance evaluation, compare and select the best plan for scheduling.
- Simulation helps to define the best strategy for a manufacturing system and carry out effectively decision-making to increase / optimize the performance of manufacturing process or the equipment utilization.
- Simulation with proposed algorithms helps to solve evaluating manufacturing effectiveness and performance measurement problem for smart factory. We can avoid extra cost by using simulation for evaluating manufacturing effectiveness and production plans.
- Simulation helps to solve (new technology) adoption problems by representing new system in digital environment.
- Simulation helps decision making and evaluation of proposed algorithms, methods and models.
- Integration of simulation and some technologies (e.g. virtual reality) meet the visualization requirements and helps factory design and layout, product and service development.
- Simulation helps to improve the efficiency of human-robot coproduction with appropriate and fast modelling solutions.
- The simulation game helps to train workers to correctly use and implement new technologies in real system. Thus, simulation provides an opportunity for training of workers to implement Industry 4.0 concept.

Modularized and flexible artifacts have already been mentioned as a technical challenge of Industry 4.0 implementation. In order to meet this challenge, (Furmann, Furmannova, & Wiecek, 2017) presented the logistic planning systems and provided interconnection of the real logistic elements by connecting the dynamic simulation with real logistics systems through intelligent sensors. Simulation provides representation of real system as synchronous with digital world through sensors. This makes it more useful to evaluate new solution.

In order to improve human-machine coproduction for implementation of Industry 4.0 technologies, (Dukalski, Çençen, Aschenbrenner, & Verlinden, 2017) stated simulation tool which part of Human Robot Coproduction Methodology. This solution consolidates visual components and structure sensor within handheld portable system.

(Xu *et al*., 2016) stated simulation optimization as a decision making tool and smart brain for Industry 4.0 / Industrial Internet in order to meet another technical challenge; intelligent decision making and negotiation mechanism. Simulation optimization provides drastically improvement the efficiency of industrial systems.

While designing the system implemented Industry 4.0 technologies, in order to meet challenges, (Zhang, Lıu, Chen, Zhang, & Leng, 2017) used the simulation combined with physics based system modelling and disturbed (near) real time process data, and thus they generated digital design of the system at preproduction phase for hollow glass production line.

5.2 Conclusions

First and foremost, the main purpose of this study was to explore and understand possibilities of simulation approach for implementing Industry 4.0 technologies in production system. In order to address the research gap and objective, in Section 1.2, the overall research question was formulated and it was divided into six smaller research questions that will serve as guidance during the whole research process. In previous section 5.1, these six research questions have been answered by discussing the previous sections of this report. Finally, thanks to these six research question, it is possible to answer to the overall research question: *What kind of possibilities do the different simulations provide for implementing Industry 4.0 technologies in case of internal production systems/processes?*

The thesis starts with a literature review about Industry 4.0 paradigm and simulation approach in order to get to know existing literature related to the topic of the research. Industry 4.0 is still a young research area, even though there is more and more research about it. It was found lots of literature related to Industry 4.0 background, challenges and technologies, and also simulation types and usage area.

In the main part of this study, the literature review and analysis, we obtained the papers related to possibilities provided by simulation for implementing Industry 4.0 technologies from three databases according to the screening criteria. As a result, simulation enables to meet the different challenges of Industry 4.0 technologies. Simulation is the one of the key approach to solve problems related to Industry 4.0 implementation and improve the production system implemented Industry 4.0 technologies. Simulation can be used for adoption of employees and new technologies to the new system in Industry 4.0 era. The simulation helps to safely train workers to correctly use and implement new technologies in real system. Furthermore, simulation provides an opportunity to evaluate and analyse proposed algorithms/programs/methods that are developed to solve many problems related to implementation of Industry 4.0 technologies, such as Big Data analytics, scheduling, production planning and control, evaluating manufacturing effectiveness, etc. without changing the real system. Also, simulation can be used to improve human-machine coproduction for implementation of Industry 4.0 in order to meet the challenge related to organizational and production fit.

It can be said this study has successfully answered the overall research question, although this study is limited to certain amount of articles. The next section will explain what kind of limitations this study has and the future research which can be done about the topic.

5.3 Limitation and Future Research

Even though limitations are an opportunity to make suggestion for the future research, there are some limitations related to the report as mentioned in the previous section. Once discussing results and concluding the research, in this section, these limitations and possible future research were discussed.

Because of the wide scope of the study, the five mount timeline has been limitation. Many different technologies, concepts and approaches has been presented but some viewpoints might not have been explained in more detailed.

Three databases that were used for literature review and analysis is another limitation of this study. However, these three databases that is large, interdisciplinary and popular were used in order to ensure a comprehensive sample that covered the most important data related to our study. More research can be done by adding other databases.

In order to know more about simulation for implementing Industry 4.0 technologies, it could be interesting do this research for a certain industry such as automotive industry. This study helps company to be aware importance of simulation approach for implementation of Industry 4.0 technologies and possibilities that simulation provides in Industry 4.0 era, and a lot of space have been left by this study for further research.

REFERENCES

Altiok, T., & Melamed, B. (2001). *Simulation Modeling and Analysis with Arena.*

Atzori, L., Iera, A., & Morabite, G. (2010). The Internet of Things: A survey. *Computer Networks*.

Bandyopadhyay, S., Sengupta, M., Maiti, S., & Dutta, S. (2011). ROLE OF MIDDLEWARE FOR INTERNET OF THINGS: A STUDY. *International Journal of Computer Science & Engineering Survey (IJCSES)*.

Banks, J., Carson II, J. S., Nelson, B. L., & Nicol, D. M. (1984). *Discrete-Event System Simulation (Forth Edition).*

Blöchl, S. J., & Schneider, M. (2016). Simulation Game for Intelligent Production Logistics – The PuLL® Learning Factory. *Procedia CIRP 54 – Elsevier*.

Buyya, R., Calheiros, R. N., & Dastjerdi, A. V. (2016). *Big Data Principles and Paradigms.* Elsevier.

Caggiano, A., & Teti, R. (2018). Digital factory technologies for robotic automation and enhanced manufacturing cell design. *Cogent Engineering*.

Dallasega, P., Rojas, R. A., Raunch, E., & Matt, D. T. (2017). Simulation based Validation of Supply Chain Effects through ICT enabled Real-Time-Capability in ETO Production Planning. *Procedia Manufacturing - Elsevier*.

Dukalski, R., Çençen, A., Aschenbrenner, D., & Verlinden, J. (2017). Portable rapid visual workflow simulation tool for human robot coproduction. *Procedia Manufacturing - Elsevier*.

Ehret, M., & Wirtz, J. (2016). UNLOCKING VALUE FROM MACHINES:BUSINESS MODELS AND THE INDUSTRIAL INTERNET OF THINGS. *Journal of Marketing Management*.

Fahmy, H. (2016). *Wireless Sensor Networks Concepts, Applications, Experimentation and Analysis.* Springer.

Fantini, P., Pinzone, M., & Taisch, M. (2018). Placing the operator at the centre of Industry 4.0 design: Modelling and assessing human activities within cyber-physical systems. *Computers & Industrial Engineering*.

Fink, A. (2014). *Conducting Research Literature Review: From the Internet to Paper.* SAGE Publications.

Fu, Y., Ding, J., Wang, H., & Wang, J. (2017). Two-objective stochastic flow-shop scheduling with deteriorating and learning effect in Industry 4.0-based manufacturing system. *Applied Soft Computing*.

Furmann, R., Furmannova, B., & Wiecek, D. (2017). Interactive design of reconfigurable logistics systems. *Procedia Engineering - Elsevier*.

Gilschrist, A. (2016). *Industry 4.0 - The Industrial Internet of Things.* Apress.

Grundstein, S., Freitag, M., & Scholz-Riter, B. (2016). A new method for autonomous control of complex job shops – Integrating order release, sequencing and capacity control to meet due dates. *Journal of Manufacturing Systems*.

Hajrizi, E. (2016). Smart Solution for Smart Factory. *IFAC Papersonline - Elsevier*.

Hermann, M., Pentek , T., & Otto, B. (2015). *Design Principles for Industrie 4.0 Scenarios: A Literature Review.*

Hsieh, L. Y. (2017). Equipment Utilization Enhancement in Photolithography Area Through a Dynamic System Control Using Multi-Fidelity Simulation Optimization With Big Data Technique. *IEEE Transactions on Semiconductor Manufacturing*.

Hwang, G., Lee, J., Park, J., & Chang, T.-W. (2016). Developing performance measurement system for Internet of Things and smart factory environment. *International Journal of Production Research*.

Kaihara, T., Katsumura, Y., Suginishi, Y., & Kadar, B. (2017). Simulation model study for manufacturing effectiveness evaluation in crowdsourced manufacturing. *CIRP Annals - Manufac-turing Technology*.

Kang, H. S., Lee, J. Y., Choi, S., Kim, H., Park, J. H., Son, J. Y., . . . Noh, S. D. (2016). Smart Manufacturing: Past Research, Present Findings, and Future Directions. *INTERNATIONAL JOURNAL OF PRECISION ENGINEERING AND MANUFACTURING-GREEN TECHNOLOGY*.

Khakifirooz, M., Chien, C. F., & Chen, Y.-J. (2017). Bayesian inference for mining semiconductor manufacturing big data for yield enhancement and smart production to empower industry 4.0. *Applied Soft Computing*.

Kocsi, B., & Olah, J. (2017). POTENTIAL CONNECTIONS OF UNIQUE MANUFACTURING AND INDUSTRY 4.0. *Logforum-Scientific Journal of Logistics*.

Kolberg, D., & Zühlke, D. (2015). Lean Automation enabled by Industry 4.0 Technologies. *IFAC-PapersOnLine*.

Laney, D. (2001). *3D Data Management: Controlling Data Volume, Velocity and Variety.* Meta Group.

Mell, P., & Grance, T. (2011). *The NIST Definition of Cloud Computing.* NIST Special Publication.

Montes, M. M. (2017). *IMPACT OF INDUSTRIAL INTERNET RELATED TECHNOLOGIES.*

Mrugalska , B., & Wyreicka, M. K. (2017). Towards Lean Production in Industry 4.0. *Procedia Engineering 182*.

Müller, J. M., Kiel, D., & Vigt, K.-I. (2018). What Drives the Implementation of Industry 4.0? The Role of Opportunities and Challenges in the. *Sustainability*.

Negahban, A., & Simith, J. S. (2013). Simulation for manufacturing system design and operation: Literature review nd analysis. *Journal of Manufacturing Systems*.

Oesterreich, T. D., & Teuteberg, F. (2016). Understanding the implications of digitisation and automation in the context of Industry 4.0: A triangulation approach and elements of a research agenda for the construction industry. *Computers in Industry*.

Rodic, B. (2017). Industry 4.0 and the New Simulation Modeling Paradigm. *Organizacija*.

Schluse, M., & Rossmann, J. (2016). From Simulation to Experimentable Digital Twins.

Shim, S.-O., Park, K., & Choi, S. (2017). Innovative Production Scheduling with Customer Satisfaction Based Measurement for the Sustainability of Manufacturing Firms. *Sustainability — Open Access Journal*.

Singh, V. P. (2009). *System Modeling and Simulation.*

Spoetti, G., & Loose, G. (2015). Transformation and Globalization in Technical, Vocational Education and Training—Which Way Should TVET Take? *International Journal of Vocational Education and Training*.

Tuner, C. J., Hutabarat, W., Oyekan, J., & Tiwari, A. (2016). Discrete Event Simulation and Virtual Reality Use in Industry: New Opportunities and Future Trends. *IEEE Transactions on Human-Machine Systems*.

Ustundag, A., & Cevikcan, E. (2018). *Industry 4.0: Managing The Digital Transformation.* Springer.

Veza, I., Mladineo, M., & Gjeldum, N. (2016). SELECTION OF THE BASIC LEAN TOOLS FOR DEVELOPMENT OF CROATIAN MODEL OF INNOVATIVE SMART ENTERPRISE. *Tehnički vjesnik*.

Wang, S., Wan, J., Li, D., & Zhang, C. (2016). Implementing Smart Factory of Industrie 4.0: An Outlook. *International Journal of Distributed Sensor Networks*.

Wang, S., Wan, J., Zhang, D., Li, D., & Zhang, C. (2016). Towards smart factory for industry 4.0: a self-organized multi-agent system with big data base d fee dback and coordination. *Computer Networks*.

Weyer, S., Meyer, T., Ohmer, M., Gorecky, D., & Zühlke, D. (2016). Future Modeling and Simulation of CPS-based Factories: an Example from the Automotive Industry. *IFAC Papersonline - Elsevier*.

Xu, J., Huang, E., Hsieh, L., Lee, L. H., Jia, Q.-S., & Chen, C.-H. (2016). Simulation optimization in the era of Industrial 4.0 and the Industrial Internet. *Journal of Simulation*.

Zhang, H., Lıu, Q., Chen, X., Zhang, D., & Leng, J. (2017). A Digital Twin-Based Approach for Designing and Multi-Objective Optimization of Hollow Glass Production Line. *IEEE Access® - Open Access (OA), Applica-tions-Oriented, All-Electronic Archival Journal*.

Zhu, X., Qiao, F., & Cao, Q. (2017). Industrial big data–based scheduling modeling framework for complex manufacturing system. *Advances in Mechanical Engineering (AIME)*.